Helideck structural requirements

Prepared by
PAFA Consulting Engineers
for the Health and Safety Executive

OFFSHORE TECHNOLOGY REPORT
2001/072
Helideck structural requirements

PAFA Consulting Engineers
Hofer House
185 Uxbridge Road
Hampton
Middlesex
TW12 1BN
United Kingdom
CONTENTS

1. INTRODUCTION 1
   1.1 Background 1
   1.2 Project Objectives 2
   1.3 Scope of Work 2
   1.4 Report Outline 3

2. EXECUTIVE SUMMARY 4

3. EXISTING INFORMATION 7
   3.1 Literature Review 7
   3.2 International Standards Organisation 8
   3.3 Classification Societies 8
   3.4 UKOOA Structural Sub-Committee Members 8
   3.5 Offshore Designers 9
   3.6 Aluminium Helideck Manufacturers 9

4. SPECIFICATIONS AND PROCEDURES - GENERAL 10
   4.1 Loading 10
   4.2 Operational 10

5. SPECIFICATIONS AND PROCEDURES - STEEL HELIDECKS 12
   5.1 Basic Specifications 12
   5.2 Classification Society Rules and Recommendations 13
   5.3 Operator Preferences 14
   5.4 Open Literature 14

6. SPECIFICATIONS AND PROCEDURES - ALUMINIUM HELIDECKS 16
   6.1 Basic Specifications 16
   6.2 Manufacturer Specifications 16
   6.3 Classification Societies 21
   6.4 Operator Preferences 22
   6.5 Open Literature 22

7. STEEL DECKS: EXPERIMENTS, EXAMPLE CALCULATIONS AND
   PREDICTIONS 23
   7.1 Plate experimental data 23
   7.2 Parameters affecting plate behaviour 24
   7.3 Plate closed-form solutions 27
   7.4 First principle procedures 30
   7.5 Plate predictions versus test results 32
   7.6 Stiffened plate experimental data 35
   7.7 Parameters affecting stiffened plate behaviour 36
   7.8 Stiffened plate closed-form solutions 37
   7.9 First principle procedures 37

8. STEEL DECKS: BASIS OF CERTIFYING AUTHORITY FORMULATIONS 38
   8.1 Introduction 38
   8.2 Comparison with test results 38
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Aluminum decks: experiments, example</td>
<td>40</td>
</tr>
<tr>
<td>calculations and predictions</td>
<td></td>
</tr>
<tr>
<td>9.1 Experimental data</td>
<td>40</td>
</tr>
<tr>
<td>9.2 Parameters affecting behaviour</td>
<td>41</td>
</tr>
<tr>
<td>9.3 Closed-form solutions</td>
<td>41</td>
</tr>
<tr>
<td>9.4 First principle procedures</td>
<td>42</td>
</tr>
<tr>
<td>9.5 Predictions versus test results</td>
<td>43</td>
</tr>
<tr>
<td>10. Basis of proposed guidance and</td>
<td>45</td>
</tr>
<tr>
<td>compliance</td>
<td></td>
</tr>
<tr>
<td>10.1 Structural criteria for plates</td>
<td>45</td>
</tr>
<tr>
<td>10.2 Structural criteria for stiffened plates</td>
<td>46</td>
</tr>
<tr>
<td>10.3 Compliance of loading specifications</td>
<td>47</td>
</tr>
<tr>
<td>10.4 Compliance of closed-form solutions</td>
<td>47</td>
</tr>
<tr>
<td>10.5 Compliance of first principle procedures</td>
<td>47</td>
</tr>
<tr>
<td>11. Recommendations and improvements</td>
<td>48</td>
</tr>
<tr>
<td>11.1 Loading</td>
<td>48</td>
</tr>
<tr>
<td>11.2 Deck response</td>
<td>48</td>
</tr>
<tr>
<td>11.3 Load factors</td>
<td>49</td>
</tr>
<tr>
<td>11.4 Analysis</td>
<td>49</td>
</tr>
<tr>
<td>11.5 Structural assessment</td>
<td>49</td>
</tr>
<tr>
<td>11.6 Supporting documentation</td>
<td>51</td>
</tr>
<tr>
<td>11.7 Risk assessment</td>
<td>51</td>
</tr>
<tr>
<td>12. References</td>
<td>52</td>
</tr>
</tbody>
</table>

**Appendices**

A HELIDECK REQUIREMENTS – ISO (Currently in Draft Form)

B HELIDECK REQUIREMENTS - AMERICAN BUREAU OF SHIPPING

C HELIDECK REQUIREMENTS - BUREAU VERITAS

D HELIDECK REQUIREMENTS - DET NORSKE VERITAS

E HELIDECK REQUIREMENTS - GERMANISCHER LLOYD

F HELIDECK REQUIREMENTS - LLOYD’S REGISTER OF SHIPPING

G STEEL DECKS: GRAPHICAL PRESENTATION OF COMPARISONS BETWEEN EXPERIMENTAL RESULTS AND CLOSED-FORM PREDICTIONS
1. INTRODUCTION

1.1 BACKGROUND

The last decade has seen a significant convergence in the main national and international guidance documents for the design and assessment of offshore helidecks.

Health and Safety Executive (HSE) guidance for helicopter landing areas was traditionally contained in Section 55 of Offshore Installations: Guidance on design, construction and certification [1]. However, the change in regulatory requirements in the U.K. towards a safety case approach has led to the downgrading in the status of this document, which was regarded as prescriptive by the Certifying Authorities, now replaced by Independent Verification Bodies.

The recommendations contained in the latest (1998) version of the Civil Aviation Authority CAP 437 [2] guidance on standards are now very similar to those of the HSE [1], reflecting 3.5 years of offshore helideck inspection by the HSE with the co-operation of the British Helicopter Advisory Board (BHAB), this task being completed in 1995. The CAP requirements do have one significant additional requirement - that an undercarriage wheel punching shear check be performed, to allow for concrete slabs used as helicopter landing areas on land.

While structural design is included in these documents, much of the guidance is concerned with operational and similar considerations. That concerned with structural design relates primarily to loading and its detailed application covering helicopters, both landing and at rest. Allowable stresses on the simple basis of permitting plastic design considerations to be applied to the deck (plating and stiffeners) are discussed, but only elastic approaches to be adopted for the main supporting members (girders, trusses, pillars, columns, etc) are allowed for.

Implicit in the descriptions given in both documents is the assumption that steel will be used as the material in construction. In neither is an appropriate code or standard referenced thereby giving the designer complete freedom in the selection of an appropriate prescriptive document. A wide variety of such documents exist such as:

- national allowable stress (working stress design - WSD) structural steel design codes and practices such as AISC [3],
- national limit state (load and resistance factor design - LRFD) structural steel design codes and practices such as AISC-LRFD [4], BS5950:Part 1 [5],
- certification authority classification rules.

Although this wide range of potentially relevant documents exists, most suffer from one limitation or another rendering them inadequate to be exploited for an entire design. For example, until Edition 9 of AISC was published, this document did not cover plastic design. Limit state codes do not provide appropriate load factors for very infrequent dynamic loads such as helicopters landing in emergencies. The classification rules nearly all relate to mobile offshore units which should not in principle make them inappropriate but seems to render them out-of-bounds to jacket designers.

However, possibly the largest limitation is the absence of relevant recommendations for aluminium decks, a number of which have already been installed on North Sea jackets. Two of the classification rules include this material, but through very minor modifications of their steel structure rules. This ignores completely the totally different approach required for the design of aluminium structures, requiring as it does very careful consideration of the manufacturing process (extruding) and construction procedure which should minimise welding or, more preferably, completely eliminate it. In contrast to steel helideck design which is usually undertaken by topsides designers, the design and manufacture of an aluminium deck and its supporting structure is indeed so different that it is frequently assigned to an independent subcontractor.
These concerns are partially addressed in the latest draft of the International Standards Organisation (ISO) Standard - ISO 19901-3, Topsides structures [6]. This states that “The helideck and its supporting structure may be fabricated from steel, aluminium alloy or other appropriate material. The following requirements are specified for a steel structure, but may be simply modified for use with an aluminium structure designed to an appropriate international or other code.” Overall, the ISO Standard appears to give a comprehensive basis for helideck design, with requirements and limitations specified in the main text - 8.4.2 Helicopter landing facilities (helidecks or heliports), along with supporting information presented in a Commentary Section - A.8.4.2 Helicopter Landing Facilities (helidecks or heliports).

However, like the HSE and CAP codes previously described, no detailed design codes are referenced or recommended.

1.2 PROJECT OBJECTIVES

In the light of the above limitations, the Health and Safety Executive requested P A F A Consulting Engineers (PAFA) to undertake a study with the following objectives:
- to identify and document available design procedures for local loading of steel and aluminium stiffened plates with particular emphasis on those in common use for the structural design of helidecks;
- to compare designs executed in detailed form by the various procedures with the results of relevant experimental investigations;
- to prepare the basis for changes to guidance which catalogues the criteria to be considered in helideck structural design and examine the existing procedures to quantify their extent of compliance;
- to recommend the most suitable procedure(s) for helideck design qualified to account for any limitations, and to catalogue improvements that are needed both individually and generically to realise procedures complying with the identified criteria.

This report was originally issued in January 1994 as OTN 92 214 [7], and has been updated by PAFA in 2001 to reflect the changes, primarily in the codes and standards, that have occurred in the intervening period.

1.3 SCOPE OF WORK

Four main tasks were identified as required to achieve the project objectives. These covered:
- existing procedures and industry preferences
- design and test data comparisons
- draft guidance and compliance
- recommendations and improvements.

The activities involved in determining ‘existing procedures and industry preferences’ were:
- undertake a literature review to identify relevant specifications, procedures and other relevant information;
- obtain from the former Certifying Authorities copies of their procedures and any relevant background documents;
- survey members of the UKOOA structural sub-committee to determine operator preferred approaches or modifications to available methods;
- obtain details from aluminium deck manufactures of their design approaches and techniques;
- document all relevant procedures.

In the process of surveying operator representatives, it became apparent that, not infrequently, they relied on designers to provide much, and occasionally all, of the input on the helideck
structural requirements. Accordingly, the scope of this task was extended to include a survey of U.K. offshore designers.

For the task concerned with ‘design and test data comparisons’, the activities undertaken were:
- compare test results and load capacities as predicted by the identified procedures
- determine the corresponding design capacities
- prepare sample calculations for each of the identified procedures
- infer the bases of the procedures.

The task ‘draft guidance and compliance’ involved the selection of suitable structural criteria for helidecks and justification for their selection. The identified procedures were examined to determine the extent of their compliance with these criteria: departures were to be noted.

For ‘recommendations and improvements’, detailed advice was to be provided on how the identified procedures could be used, in a modified form if necessary, in order to comply with the selected criteria.

1.4 REPORT OUTLINE

An Executive Summary is presented in Section 2.

Section 3 is concerned with sources of information and covers that obtained through normal literature outlets and through interviews with operator and designer representatives. All aspects are covered, test results, analysis and design procedures, and user modifications to applications.

In Section 4, design requirements and procedures common to helidecks constructed from either steel or aluminium are considered. These are primarily concerned with loading and operational aspects.

Section 5 presents details of the procedures for the design of steel decks identified in the review and the modifications introduced by operators and designers. In Section 6, similar information is reported for aluminium decks.

Section 7 reports test results available for steel decks. The main parameters affecting behaviour are discussed. Sample calculations are presented using the identified procedures and first principle approaches. Comparisons between tests and predictions are conducted.

In Section 8, the bases of the Classification Society rules and recommendations for decks are examined.

Section 9 discusses test results available for aluminium decks. The main parameters affecting behaviour are discussed. Sample calculations are presented using the identified procedures and first principle approaches. Comparisons between tests and predictions are reported.

Section 10 discusses the structural requirements for plates and stiffened plates to form the basis of proposed guidance. Compliance of the existing requirements with those proposed is examined.

In Section 11, recommendations are made for improving existing requirements and further needs are identified.
2. EXECUTIVE SUMMARY

Surveys of the literature and members of the UKOOA Structural Committee were conducted to obtain information, data, and specifications relevant to the design and construction of offshore helidecks.

Limited but relevant test data and specifications for steel helidecks have been secured. There is considerable variety in the specifications on loading although that from HSE guidance and CAP 437 dominates application.

Implicit in all current requirements is that steel will be the construction material. Even in two Classification Society requirements, and also in the proposed ISO Topside Structure Standard requirements that explicitly allow for the use of aluminium, the inherent structural configuration is that of a steel deck.

Details of test data relating to steel helidecks subjected to simulated wheel loads are presented. Their lateral load versus permanent set curves are reconstituted. Two distinct phases exist. The first is essentially elastic and involves no permanent set. Nevertheless, non-linear geometry effects are present in the form of membrane (in-plane) stresses. These large deflection effects enhance the load capacities for a given deflection compared with traditional assessments. The second is approximately linear although it involves the onset and spread of material yielding. Permanent set results from loading into this range.

The parameters influencing the response of locally loaded steel decks are reviewed. Those of panel slenderness and panel width to patch width ratio have the greatest influence. Material properties are of significance but less so than the geometry variables. Initial geometrical distortions of the panels affect their initial stiffness while residual stresses, another result of welding between the plating and the stiffeners, seem mainly to affect the load on which yielding occurs and, therefore, the onset and extent of permanent set.

The predictions of five closed-form procedures (by which load capacities can be directly determined given geometry and material properties) for the design of helideck plating are compared with the test results. Three of the procedures emanate from relevant Classification Societies and are found to predict load capacities less than those at which permanent set can be expected to develop. At best, the accuracy of the predictions is 15%, with the test values averaging some 38% higher than the best predictions. One of the closed-form solutions is a graphical fit to the permanent sets found in the tests and by numerical results produced contemporaneously: it demonstrates a close fit to the results. The final closed-form solution is a multiple-regression fit to the permanent set data. It provides a reasonable estimate of the load at which permanent set occurs but then suggests a faster rate of growth of permanent set than is observed in the results.

Two first-principle procedures are developed and their predictions compared with the test results. Both are based on a plate strip representation, one limiting the maximum stress to yield, the other exploiting the full plastic hinge capacity of the plating. Membrane stresses are ignored. Both demonstrate an accuracy of prediction equal to that of the best of the Classification Society formulations, i.e. 15%, although they under-estimate the loads for the onset of permanent set by factors of 4.4 and 2.2 respectively. These particular comparisons helped to identify an aspect ratio effect not previously noted which was that panels of aspect ratio unity were significantly stronger than panels of aspect ratio two or more, at least for patch load aspect ratios of two. Accounting for this improved the accuracy of the relevant predictions to 12%.
The Classification Society formulations were examined together with their comparisons with the test data with a view to identifying their bases. No obvious criteria could be discerned.

Test data for an aluminium helideck was made available to the study. The tests were only briefly described. Nevertheless, it was possible to identify the main failure modes which nearly all involved failure of the stiffener web. This was predominantly web buckling, with web crippling being a contributing cause in several cases. A database of web crippling test results was established in order to select the most suitable of the number of formulae available for present purposes.

Structural criteria are examined for emergency and heavy landing conditions. This requires consideration of the definition of these loading categories: they are found wanting. The emergency condition is identified as the ‘crash landing’ for which the undercarriage collapse load is the relevant design condition. This is judged rare enough to allow even significant permanent set to occur in the deck plating but not in the stiffeners in order not to hamper rescue and fire-fighting efforts. The heavy landing criterion is provisionally proposed as a vertical descent at 2.4 m/s whilst two-thirds airborne (i.e. two-thirds of weight supported by rotor lift). Under these conditions, a permanent set smaller than normal construction tolerances is permitted. Load factors and analysis methods are selected consistent with the chosen permanent set criterion. These involve closed-form solutions, and first yield and plastic hinge approaches.

Recommendations for guidance are prepared based on the identified criteria and presented separately. A number of these recommendations are reflected in the proposed ISO Standard for Topside Structures.

Compliance of regulatory and Classification Society specifications with the proposed guidance is limited. The study has shown that suitable structural assessment options are available but these require some manipulation to convert them into a format more convenient for design.

The proposed helicopter landing loading specification departs so significantly from those presently in place that there is no advantage in trying to simply modify these. New requirements are needed placing an onus on helicopter manufacturers to provide the relevant information. The proposed vertical descent velocity needs statistical verification.

The requirements concerning ‘deck response’ factors and their implementation are both inconsistent. Plating and stiffened plating of helidecks normally have natural periods significantly shorter than the ‘rise time’ associated with helicopter landings, some 0.05 to 0.1 s. However, although aluminium decks are the most susceptible to ‘deck response’, the relevance of the data on which present requirements are based is questioned in the light of the relatively high stiffness of the landing deck used to generate these data. Additionally, for aluminium decks, the sealant used in the joints between planks can contribute towards the damping.

A static analysis approach is proposed consistent with present requirements. However, until the effects of dynamics and strain rate on yield, which is relevant for steel but not aluminium, are quantified, the inherent safety levels of helidecks and any differential between those of steel and aluminium cannot be determined.

Present structural assessment criteria assume helidecks to be constructed of steel or aluminium equivalents. No provisions are made for the assessment of the aluminium helidecks currently in relatively widespread use. The proposed guidance specifically caters for aluminium decks but further development is required to produce the closed-form type of solutions favoured by Classification Society.

None of the present Classification Society requirements appears to allow permanent set to develop in the plating although one authority ostensibly used such a criterion in the development of its specification. Recommendations to modify the existing requirements have not been made because none of them correctly captures the effect of one of the most important
parameters affecting the behaviour of patch loaded plates, namely, the panel width to patch width ratio. Further, the accuracy of the requirements does not justify effort since none is as accurate as some simple plate strip solutions developed during the course of the work. It has not been possible to determine the basis of the requirements since not one of them has documented the development of its procedure despite the fact that in some cases extensive computing resources were used and considerable effort devoted to producing the published closed-form solutions.

A plastic hinge approach is proposed for the design of stiffened decking, but no permanent set is permitted. None of the present requirements allows such an approach to be adopted. In two cases, closed-form solutions are offered for stiffened plating assessment, but these are elastic in origin and thus cannot be modified to realise a plastic hinge solution. Equivalent closed-form solutions based on plastic hinge theory can be developed for stiffened plating as demonstrated in the present work in relation to a plate strip.

Web buckling or crippling is a likely failure mode for some stiffened aluminium decks and steel decks with trapezoidal stiffeners. Present requirements do not consider this possibility. Procedures used and developed in this work can be exploited to cater for this eventuality.

In the draft ISO Standard:
- Deck plate may be designed to allow a permanent set not exceeding 0.025 of the plate width under helicopter emergency landing loads.
- Stiffening elements and the supporting structure may be designed using plastic hinge theory.
- Cantilever elements should be designed using a first yield solution.
- Webs of stiffeners should be assessed locally under landing gear loads due to helicopter emergency landings and at supports.
- Closed form solutions may be used for web crippling.

The conduct of a risk assessment on helideck failure is recommended. If necessary, quantitative risk assessment could be undertaken along with a reliability study of loading and structural response to quantify the possibility of the occurrence of deck rupture leading to fuel leakage. Jointed aluminium decks seem more susceptible than steel decks in this respect.
3. EXISTING INFORMATION

3.1 LITERATURE REVIEW

The HSE document [1], CAP 437 [2] and draft ISO Standard [6] are, as indicated in the Introduction, primarily concerned with the loading specification for helidecks and with general guidance on structural design. Other literature relevant to this topic includes experimental results for plates and stiffened plates subjected to local lateral loads, Classification Society rules and regulations, closed-form solutions for design/prediction of plates subjected to local loading, and any background information to classification rules and closed-form solutions.

The following documents were reviewed in the course of the work:

- a paper by Clarkson reporting tests on grillages in which concentrated loads are placed directly over the stiffeners [8];
- a paper by Haslum primarily concerned with the design of stiffened plating subjected to tyres of dimensions greater than the stiffener spacings. Yield in the plate is used as the stress limit in an analytical solution to a beam strip model of plating behaviour, and a shear lag effective width or stiffener spacing is used in the determination of stiffener flexural properties. No interaction between the two stress systems is considered [9];
- a report by Sandvik which advances the investigation of Haslum by taking the loading beyond the elastic limit and developing a design approach based on test results in which an artificial allowable stress of twice yield is introduced [10];
- a paper by Jackson and Frieze on a combined experimental and numerical evaluation of steel helidecks subjected to wheel loads and exploitation of the results to provide closed-form empirical design data in graphical form [11];
- a paper by Hughes that exploits some analytical results for plates subjected to various forms of concentrated loads and then develops a design equation through a multiple regression fit to the test results presented by Jackson and Frieze [12]. Note that the equation presented in this paper and which formed the basis of the comparisons presented in the draft version of this report has been modified in accordance with the latest version of the diskette accompanying [16];
- a paper by Viner providing the basis of the family of curves derived by Lloyd’s Register of Shipping for plates subjected to vehicle loads. Extracts of this same reference were provided by Lloyd’s following a formal approach to them as part of this project [13];
- a paper by Vassilikos and Dowling describing an analytical solution for stiffened plates subjected to patch loads positioned over stiffeners. Behaviour into the yield regime is examined combined with large deflection effects [14];
- a PhD thesis by Vassilikos giving full details of the study summarised in the preceding paper [15];
- a revision of the paper by Hughes in condensed form accompanied by a computerised version of the procedure on a diskette [16];
- a report by Zhang of tests on two steel decks and complementary computer studies involving trapezoidal and bulb flat stiffeners [17];
- a paper by Lehmann and Zhang summarising the work described in the previous document [18];
- a report by Harding comparing different methods for measuring helicopter wheel loads upon landing, both normal and emergency, including drop tests up to undercarriage failure [19];
a companion paper to the preceding one by Mainstone reporting on the loads measured during landing and the reactions within the instrumented supporting structure of the concrete slab on which the landings took place [20];

a confidential report by Deady fitting a statistical distribution to descent velocities of shipborne helicopters [21];

a paper by Garron concerning helicopter deck loads on warships largely based on landing gear performance [22];

API RP2L recommended practice for helidecks for fixed offshore structures (extracts) [23];

U.S. Office of Aviation and Transportation. Offshore heliport design guidance [24];

U.S. Department of Transportation. Federal Aviation Administration. Advisory Circular on heliport design [25];

U.S. Structural Design Guidelines for heliports [26].

3.2 INTERNATIONAL STANDARDS ORGANISATION

The ISO Standard for Topside Structures - ISO 19901-3, is currently in draft format [6]. Relevant extracts from this draft document are reproduced in Appendix A.

The layout of the document is similar to that of the HSE and CAP guidelines, with the emphasis of this Standard being on a recommended approach to structural design of helidecks, rather than on the publication of detailed formulations for such design.

3.3 CLASSIFICATION SOCIETIES

Most Classification Societies with jurisdiction in the U.K. sector of the North Sea have classification notes available that include helideck specifications. Because the main duties of some of these Authorities is primarily classification of floating structures, the helideck specifications generally only appear within rules for mobile offshore units and the like. Two, however, Lloyd’s Register of Shipping and Det Norske Veritas, have adopted identical specifications for fixed platforms and these are published in the relevant documents.

The authorities relevant to this current investigation are:

- American Bureau of Shipping (ABS)
- Bureau Veritas (B.V.)
- Det Norske Veritas (DNV)
- Germanischer Lloyd (GL)
- Lloyd’s Register of Shipping (LRS).

All the authorities were approached to obtain extracts of their relevant classification rules [27, 28, 29, 30, 31]. These were provided and are presented in Appendices B to F. Background information was also sought from these bodies but no detailed work was made available.

3.4 UKOOA STRUCTURAL COMMITTEE MEMBERS

A survey was conducted amongst members of the UKOOA Structural Committee. Initially they were sent correspondence containing a series of questions relating to the procedures adopted by their organisations. Follow-up discussions and/or meetings were held with most during which details relating to previous and current designs were considered. In some cases, relevant design briefs (or summaries thereof) were provided [32, 33, 34, 35, 36, 37].
3.5 OFFSHORE DESIGNERS

During discussions with the UKOOA Structural committee members, it became clear that some Operators relied on platform designers to provide the relevant helideck specifications. Discussions were then held with three of the offshore designers:

- Brown & Root
- John Brown Engineers & Constructors
- Kvaerner Earl & Wright.

The second of these organisations provided detailed example specifications [38].

3.6 ALUMINIUM HELIDECK MANUFACTURERS

Alcan Offshore, a division of British Alcan Extrusions Ltd, has been active in promoting the use of aluminium offshore. This has resulted in the production of brochures, the presentation of papers at conferences [39] and the development of an extensive design guide [40]. It has also prepared a list of manufacturers and fabricators supplying products to the offshore industry identifying those that can supply helidecks [41].

Two of the manufacturers active in the supply of helidecks were contacted. They were NCMP Ltd and Linkletters PSF Co Ltd.

NCMP Ltd has developed an extruded closed section specifically for helidecks and is understood to have built a significant number of the helidecks in the U.K. sector of the North Sea. It also seems to have played a major role in the preparation of the first relevant specification for offshore helidecks which was developed for Marathon’s Brae B platform.

Considerable background information was reviewed during discussions with the company covering material selection, product production, fabrication, analysis, design considerations, and installation aspects. No written material was made available.

Linkletters Co Ltd is licensed by Merlin Teknolgi AS to manufacturer the latter’s Convdeck and Safedock helideck systems. Merlin [42, 43, 44] provided relevant reports including one concerned with tests to failure of the Convdeck system.
4. SPECIFICATIONS AND PROCEDURES - GENERAL

4.1 LOADING

CAP 437 and HSE guidance have dominated the loading specifications used. As noted earlier, these are very similar with both now requiring consideration of a ‘heavy landing’ scenario to be considered. This requirement is similar to the emergency landing condition except that a factor of 1.5 times maximum take-off weight (MTOW) is used in place of the 2.5 factor applicable in the emergency case. In the draft ISO standard, similar requirements to HSE/CAP are proposed, although, at present, there is no requirement for a heavy landing.

Heavy and emergency landings are not precisely defined in either guidance or CAP 437 but in general terms can be interpreted as follows:
- **Heavy Landing** - likely to arise on average approximately once a year and to result from unfavourable combinations of factors such as poor weather conditions, minor mechanical problems and slight pilot mishandling;
- **Emergency Landing** - expected only once in a lifetime and to result from such serious events as loss of power, major pilot mishandling, or fouling of installation equipment upon landing or take-off.

Tables 4.1 and 4.2 summarise the loading requirements for the two specifications. Also tabulated are those found in the classification notes of the Classification Societies listed in Section 3.2, the relevant extracts for which are presented in Appendices B to F. Table 4.1 is concerned with the load specification during helicopter landings while Table 4.2 relates to helicopters in the stowed position.

From both tables, it is seen that a considerable variation of requirements exists between all the specifications with variations particularly on:
- the factor on MTOW (M) for emergency landing conditions
- whether a deck response factor is considered
- the level of superimposed load considered simultaneously or separately
- whether a lateral load is considered simultaneously with the emergency-landing load.

Without taking into account the effects of allowable stress levels and permitted design approaches, for example, plastic hinge theory, it is not possible to quantify the effect these differences will have on the design of a deck and its supporting structure.

4.2 OPERATIONAL

Several operational considerations affect the structure directly or indirectly. One of the main requirements is for drainage. A slope of 1:100 is widely adopted for this although it is acknowledged, for steel decks in particular, that this is inadequate to promote drainage when the distortions in the plating arising from fabrication are taken into account. The latter are often specified not to exceed a value in the order of the plate panel width divided by 200 and can be exceeded on occasions.

A second major requirement concerns the use of nets. These are in wide use. With some non-slip surfaces now available, particularly on aluminium decks, it appears possible to dispense with nets. However, there appears to still be a demand even in these circumstances because of the security afforded by them for personnel embarking and disembarking. They are, however, possibly hazardous for helicopters fitted with skids which can become entangled in the net. They also inhibit the use of wheeled means of transport.
## Table 4.1
Helideck Loading Specifications - Helicopter Landing

<table>
<thead>
<tr>
<th>Authority</th>
<th>ISO</th>
<th>CAP</th>
<th>HSE</th>
<th>ABS</th>
<th>B.V.</th>
<th>DNV</th>
<th>GL</th>
<th>LRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Landing</td>
<td>-</td>
<td>1.5M</td>
<td>1.5M</td>
<td>-</td>
<td>1.5M</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Emergency Landing</td>
<td>2.5M</td>
<td>2.5M</td>
<td>2.5M</td>
<td>1.5M</td>
<td>3.0M</td>
<td>2.0M</td>
<td>1.5M</td>
<td>1.5M</td>
</tr>
<tr>
<td>Deck Response Factor</td>
<td>1.3</td>
<td>1.5(4)</td>
<td>1.3(4)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Super-imposed Load kN/m²</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>2.0(5)</td>
<td>2.0(5)</td>
<td>As normal class</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Lateral Load</td>
<td>0.5M</td>
<td>0.5M</td>
<td>0.5M</td>
<td>-</td>
<td>-</td>
<td>0.4M</td>
<td>-</td>
<td>0.5M</td>
</tr>
<tr>
<td>Wind Load</td>
<td>Max.</td>
<td>see Sect’n</td>
<td>Normal</td>
<td>-</td>
<td>vel = 30m/s</td>
<td>vel = 25m/s</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

M Maximum take-off weight

(1) Or manufacture’s recommended wheel impact loads

(2) For design of plating

(3) For design of stiffening and supporting structure

(4) Additional frequency dependent values given for the Chinook helicopter

(5) Considered independently

## Table 4.2
Helideck Loading Specifications - Helicopter at Rest

<table>
<thead>
<tr>
<th>Authority</th>
<th>ISO</th>
<th>CAP</th>
<th>HSE</th>
<th>ABS</th>
<th>B.V.</th>
<th>DNV</th>
<th>GL(1)</th>
<th>LRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-weight</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>1.5M</td>
<td>-</td>
</tr>
<tr>
<td>Super-imposed Load kN/m²</td>
<td>2.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.49</td>
<td>0.5</td>
<td>As normal class</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Wind Load</td>
<td>100 yr</td>
<td>see Sect’n</td>
<td>Normal design</td>
<td>Normal design</td>
<td>vel = 55m/s</td>
<td>vel = 50m/s</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Platform Motions</td>
<td>As calc.</td>
<td>As calc.</td>
<td>As calc.</td>
<td>As calc.</td>
<td>As calc.</td>
<td>Vert.</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

M Maximum take-off weight

(1) Fixed platforms, for floating platforms also include lateral load of 0.6 (M + W) where W is deck weight in place of platform motions.
5. SPECIFICATIONS AND PROCEDURES - STEEL HELIDECKS

5.1 BASIC SPECIFICATIONS

The basic specifications adopted for helideck design depend on the age of the unit since the availability of relevant documents has changed since the first decks were installed. It is to be noted that a number of timber helidecks still exist although various forms of protection, particularly against fire, have been applied over the years in line with changes in guidance. All new designs, however, are of steel or aluminium.

The reasons for selecting steel in preference to aluminium for the deck (plating and stiffeners) varied. Some of these were:
- concern for the problems inherent or allegedly so in the use of aluminium such as thermic sparking and low melting point;
- initial cost benefits;
- designer familiarity;
- for small low cost platforms, simplicity required.

For the older decks, the following specifications and codes have been used:
- deck loading to CAA requirements, probably equivalent to CAP 437 (although it should be noted that the 1981 version differs significantly from the latest version of CAP 437);
- steel specification BS 7668 [45], superseding BS 4360 in 1994;
- for emergency landing
  - deck and stiffeners by plastic hinge theory;
  - supporting structure by elastic theory ensuring no permanent deformations occur.

For more recent designs, the above loading and material specifications are in frequent use. However, various interpretations are applied to the guidance and CAP 437 requirement that ‘plastic design considerations may be applied for the deck, i.e. plating and stiffeners only, but elastic considerations must be applied to the main supporting members’. Table 5.1 presents some of these, all based on the guidance loading requirements.

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>Component</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plating</td>
<td>100%</td>
<td>Doesn’t</td>
<td>Doesn’t</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Landing</td>
<td>Stiffeners</td>
<td>100%</td>
<td>Doesn’t</td>
<td>Doesn’t</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support structure</td>
<td>90%</td>
<td>Doesn’t</td>
<td></td>
<td></td>
<td>AISC incl. 1/3rd</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Landing</td>
<td>Plating</td>
<td>90%</td>
<td>100%</td>
<td>75%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td></td>
<td>Plastic</td>
<td>Elastic</td>
<td>Plastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stiffeners</td>
<td>90%</td>
<td>100%</td>
<td>AISC but no 1/3rd</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td></td>
<td>Plastic</td>
<td>no 1/3rd</td>
<td>Plastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Support</td>
<td>100%</td>
<td>100%</td>
<td>AISC but no 1/3rd</td>
<td>AISC incl. 1/3rd</td>
</tr>
<tr>
<td></td>
<td>Elastic</td>
<td></td>
<td>Elastic</td>
<td>no 1/3rd</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1
Helideck Allowable Stresses
Loading In Accordance with HSE Guidelines
In the table, columns 3 to 6 list four combinations (I to IV) of ‘allowable stresses’ that have been adopted by designers or operators for the design of steel helidecks.

Combination I, for example, exploits the full elastic capability of the plating for the heavy landing condition, and nearly full plastic strength under the emergency landing condition. The stiffeners do not exceed the elastic limit although this is fully exploited for the more onerous of these requirements. On the other hand, combinations II and III consider the heavy landing condition superfluous. Combinations III and IV differ in their appreciation as to whether the one-third increase in stresses, if these are predominantly due to environmental forces, is permitted for designs to AISC [3].

From the table it is thus seen that little consistency exists in the application of the HSE and CAP requirements. Permanent set is never considered. Strain rate effects on yield stress are not accounted for. The heavy landing condition is widely recognised as a superfluous check. The deck response factor is seemingly not consistently applied.

5.2 CLASSIFICATION SOCIETY RULES AND RECOMMENDATIONS

As indicated above, the relevant extracts of these are presented in Appendices B to F. It is seen that in general these requirements are only concerned with the deck plating or the deck plating and the stiffening, the supporting structure being covered by normal design approaches.

The implications of these rules for deck design are examined in Section 7. Here, brief summaries of the design procedures and their bases where available are presented. In general, the approaches for deck design are ‘closed-form’ solutions, that is, given the overall geometry, the material properties, and the load, the deck plate thickness or the stiffener section modulus can be found directly from the application of a set of equations or through a combination of equations and graphical information. Otherwise, a ‘first principle’ approach is used involving conventional structural analysis and design procedures.

American Bureau of Shipping: This is based on design from first principles.

Bureau Veritas: This recommends calculation of loads according to “Evaluation of loads on offshore units and installations or according to applicable national standards.”

Det Norske Veritas: For the plating, this approach seems to use a nominal elastic limiting stress greater than yield stress. It accounts explicitly for panel aspect ratio, panel width to patch width ratio, panel width to patch length ratio, and load and panel width. For the stiffeners, the required section modulus is a function of the load, stiffener length, the patch width to panel width ratio, and the flexibility of the girders supporting the stiffeners. The limit on stress is approximately half that applicable in the design of the plating.

Germanischer Lloyd: Here the ratios of patch area to panel area, and panel aspect ratio are explicitly accounted for in the design of the plating. Stiffener design is from first principles.

Lloyd’s Register of Shipping: For plating design, this uses a multi-criteria approach involving total plate deflections, permanent set, and alternating stress range to limit fatigue damage, to generate a family of curves which are a function of patch aspect ratio, panel aspect ratio, and panel width to patch width ratio. Stiffener design is from first principles.
5.3 OPERATOR PREFERENCES

The survey of operators covered both loading requirements and design approaches including the use of Classification Society rules: class rules were rarely adopted. The fact that helidecks designed in the U.K. are generally for fixed platforms while the Classification Society rules apply primarily to floating units may be an important factor in this respect.

It is also clear that some operators rely entirely on design contractors to prepare appropriate helideck design briefs. Others either independently prepare their own or with the assistance of a designer. When the former appeared to be the case, it seems that it had probably resulted from an amalgamation with time of specifications promoted by designers. This did seem to result in specifications becoming more rigorous as requirements once incorporated were rarely deleted while new ones were readily added.

5.4 OPEN LITERATURE

Few complete design procedures have appeared in the public domain outside the Classification Societies rules. For the design of plating, the two most relevant ones are by Jackson and Frieze [11] and by Hughes [12], both based on the results reported by the former. The combined test and numerical study undertaken by Jackson and Frieze examined:
- plate aspect ratio 1, 2, 4 and 8
- width to thickness ratio 31.5 and 63.0
- panel width to patch width ratio 1.8, 3.0, 3.6 and 6.0
- initial plate distortions and welding residual stresses.

The numerical results were used to obtain confirmatory solutions before completing the range of parameters covered by the experimental work.

Jackson and Frieze used interpolation and extrapolation of the test and numerical results to produce three families of load versus plate permanent set design curves for three levels of permanent set. Hughes used a multiple regression fit to the results to generate an equation between load and permanent set. The equation is, referring to Figure 5.1,

\[ P = \phi \left[ \frac{10.45 \mu}{\beta^2} + \left( 0.34 + \frac{3.56}{\beta^{1.6}} + 0.23 \left( \frac{\mu}{1 - \mu} \right)^{0.8} \right) \delta_p^{1.1} \right] \]  

where
- \( P \) = patch load
- \( \phi = 1 - 0.8 \left[ \frac{AB}{(A^2 + B^2)} \right]^2 \)
- \( \mu \) = \( \sqrt{AB/b} \)
- \( \beta = \frac{b}{t} \frac{\sigma_y}{E} \)
- \( \delta_p = \frac{w_p}{t} \beta \)
- \( a, b \) = panel dimensions
- \( A, B \) = patch dimensions
- \( t \) = plate thickness
- \( \sigma_y \) = yield stress
- \( E \) = elastic modulus
- \( w_p \) = permanent set at plate centre.

Neither of the these references provides guidance on a design approach for the stiffeners, although Jackson and Frieze indicate the criterion for such design is for the stiffeners to remain elastic, partly based on a repair policy which considered the replacement of plating acceptable but not that of stiffeners as well as plating. This was the philosophy adopted by the body that supported the work at the time, namely, MOD. This reason is not necessarily valid in circumstances where safety is the over-riding criterion and not the serviceability of the deck following an emergency landing.
Figure 5.1
Patch Load Layout and Notation
6. SPECIFICATIONS AND PROCEDURES - ALUMINIUM HELIDECKS

6.1 BASIC SPECIFICATIONS

The aluminium used offshore is a heat-treatable alloy containing magnesium and silicon designated 6082 T6. This apparently offers the best combination of strength and corrosion resistance in marine environments for extruded sections, from which decks are constructed, as well as for sheets and plates. It does however suffer from an important limitation relating to its weldability. This is the reduction in strength that occurs as a result of welding, to 50% of its unwelded strength. This has a major impact on detailing and for on-site erection procedures.

The first major aluminium helideck was installed on Marathon’s Brae B platform in 1984. Since then an increasing number of such units have been installed, nearly all with steel supporting structures. The reasons given for selecting aluminium in preference to steel for the deck (plating and stiffeners) were:

- weight saving
- lifetime cost benefits
- readily heat shielded if required.

For the earliest decks, a relevant British Standard, CP 118 [46], was available. However, this did not adequately cover the full design requirements necessary for an aluminium deck. The appropriate specification seems to have been developed through close co-operation between Marathon and the selected contractor NCMP Ltd. It then seems to have become the basis for a number of other specifications for aluminium helidecks in the U.K. sector of the North Sea. The specification was not made available to this study.

With the licensing agreement now in place between Linkleters and Merlin Teknologi, it is likely that an alternative specification will be available. Also, CP 118 has been superseded by BS 8118 [47] providing an appropriate update of relevant design information. However, even this recent document does not seem to provide a suitable approach for the proof checking of extruded sections as will be discussed in Section 6.2.

As for steel decks, HSE [1] and CAP 437 [2] are followed to establish the loading requirements for aluminium decks. The remainder of the design process for an efficient end product requires early involvement of the independent designer/contractor since it is significantly more complex than for the equivalent steel product. This requires close co-operation between the client, the designer and the manufacturer to realise a product generally optimised with respect to weight.

6.2 MANUFACTURER SPECIFICATIONS

Detailed manufacturer specifications for helideck units have not been made available to the study. However, visits to a helideck fabricators works (NCMP Ltd) and to an extrusion plant (Alcan Speciality Extrusions) provided considerable insight to the process of deck unit manufacture. Discussions with a second fabricator (Linklaters PSF Co Ltd) and their provision of design calculations, and a test report from their licensee Merlin Teknologi supplemented this.

The deck units promoted by NCMP Ltd and Linklaters PSF Co Ltd are representative of the two main competing ‘plank’ options in use in aluminium helideck construction. These are illustrated in Figure 6.1 from which it can be seen that they constitute ‘closed’ or ‘open’ cross-sections respectively. They are approximately 0.3 m in width and both use a similar tongue and
groove arrangement for joining their longitudinal edges with a flexible chemical, fuel and temperature resistant sealant. They are clamped or bolted to their supporting cross-beams.

![Figure 6.1 Typical Deck Cross-Section](image)

Each plank offers its own production and structural advantages. The closed unit is more difficult and thus more expensive to produce but is torsionally stiff. The open section is easier and cheaper to produce, and is lighter in weight. However, it is torsionally weak and requires spreader beams to help it distribute localised loading to adjacent planks. Because of its method of production, the closed alternative requires an additional check in the form of a proof test, which is not necessary in the case of the open section. Some of the design and production features of the planks are discussed in the following.

The extrusion process produces planks. This requires the preheating of aluminium billets to around 500°C and then the forcing of the aluminium through a die. This forcing generates pressure, which combined with the temperature causes the aluminium to flow and thus take up the shape of the die. By continuing to apply the pressure, a major proportion of the billet can be extruded to produce sections of lengths dependent on the original billet size and the cross-sectional area of the plank. For the closed section shown in Figure 6.1, lengths of 14 m are typical.

Almost immediately following the extruding (within 1.5 to 2.0 seconds), the section is quenched to approximately ambient conditions. This avoids the precipitation of the hardening elements within the alloy. The sections following extrusion are quite true to shape but are not straight axially.

Thickness is checked at this stage and sections falling outside the tolerances are rejected. Initially dimensions are close to their lower limit but as the die wears with use, the thicknesses gradually increase until the upper tolerance limit is reached. Out of straightness is rectified by stretching the sections by up to some 2% strain. This process invariably requires crushing of the ends by the clamps, which effect the stretching. The crushed ends are cut off and recycled.

The final stage of the process is the T6 heat treatment that enables the material to achieve its full strength properties. The treatment can be carried out at temperatures between about 150 and 220°C and is a function of the exposure time. The optimum seems to be around 170°C which is to be maintained for 9 hours. This process results in the precipitation of hardening elements. The shape of the extrusion does not change during heat treatment.

Following heat treatment, tensile specimens are taken to determine the 0.2% proof stress, the tensile strength and the strain at rupture.

There are several features of the process that are particular to the closed section that need extra consideration. The most important is that to create a closed section, the die must initially
separate the incoming aluminium into several channels in order that it will flow uniformly around the various parts of the die. This is illustrated in Figure 6.2, which shows the ‘male’ section of the die surrounded by five main channels. To ensure the flow into the internal webs of the section is uniform, secondary channels are introduced ‘behind’ the lines of the webs as illustrated in Figure 6.3.

![Figure 6.2](image1.jpg)

**Figure 6.2**
Male component at closed section die showing slots to create the internal webs and the main channels for initially separating the aluminium.

![Figure 6.3](image2.jpg)

**Figure 6.3**
Male component of closed section die showing the secondary flow channels.
Figure 6.4 shows the female component of the die with the male component behind. The asymmetry of the upper flange to cater for the tongue and groove fixtures on each edge is clearly visible.

Figure 6.4
Female component of closed section die showing tongue and groove asymmetry of upper flange. The male component is in the background.

Figure 6.5
The first material through a die is mis-shapen
Figure 6.6
The extrusion after trimming and prior to straightening

Figure 6.7
The early stages of a drift test on a length of closed section
The first material to pass through a die is usually misshapen (Figure 6.5). Maximum utilisation of material from a billet is achieved by introducing them as continuously as possible. However, as the aluminium at the beginning of a subsequent billet is forced to mix with that at the end of the preceding billet, incomplete fusion occurs. This is removed by the trimming of an appropriate length of mixed material either side of the join, the extent being largely determined from experience (Figure 6.6).

Incomplete fusion results from the mixing of material from different billets. It can also occur within a billet along the fusion lines of the aluminium where the separated flow is forced to mix again. Incomplete fusion in this case is rare but is checked for by the cutting and testing a short specimen from each end of an extrusion. This is referred to as the ‘drift test’ and involves placing each ‘opening’ of a closed section onto a cone and applying load (Figure 6.7) until it fractures. Each fracture is examined to determine if it occurs in the parent material or along a fusion line. The latter is usually distinguished by its straightness and smooth fracture surface (Figure 6.8).

Drift tests are performed on every closed section by Alcan Speciality Extrusions whether specified by the fabricator or not. Open sections do not entail flow separation in their production so are not subject to this particular test.

### 6.3 CLASSIFICATION SOCIETIES

Two of the class requirements issued for helidecks have an allowance for the alternative use of aluminium. This can be seen in the extracts of the relevant DNV and LRS documents in Appendices D and F. DNV makes allowance through its material factor $f_1$ and would appear to result in the same thickness of plating as required for a steel deck of the same yield or 0.2% proof stress. The LRS rules lead to aluminium plating basically 40% thicker than the equivalent steel deck. They also specify a minimum inertia for any stiffening elements in addition to the set stress limits: only stress limits apply in the case of stiffening to steel decks.
A problem with application of the DNV rules to aluminium decks is that they assume a configuration for such decks similar to that which would be employed for a steel structure. This is reflected in their use of formulae for which the patch load must be of dimensions less than the stiffener spacings. As can be deduced from the above, aluminium decks consist of extruded planks with webs at some 0.1m spacing, which is only one-third of a typical helicopter tyre footprint dimension.

6.4 OPERATOR PREFERENCES

Most aluminium decks have a steel support structure. However, one current design involves an aluminium support structure as it is positioned above accommodation quarters and is thus felt to be suitably shielded from fires and blasts and their effects. As for the deck, the use of an aluminium support structure is not just a replacement of the equivalent steel configuration but again requires early involvement of the potential sub-contractor. As indicated, the main reason for this is the reduction in strength that occurs in the alloy as a result of welding. The completely different details that are generated in an aluminium structure as a result are difficult for a structural designer experienced in steel to produce effectively.

6.5 OPEN LITERATURE

Although not strictly a specification, the Alcan/Wimpey design guide on the use of aluminium in offshore structures is available. It does not however include the form of decks currently in use as offshore helidecks.

No other relevant material has been identified.
7. STEEL DECKS: EXPERIMENTS, EXAMPLE CALCULATIONS AND PREDICTIONS

7.1 PLATE EXPERIMENTAL DATA

From the literature review reported in Section 3, only two sources of experimental data for plates were identified, namely, those of Jackson and Frieze [11], and Zhang [17]. Both reported simulated wheel load tests on stiffened steel grillages and complementary elasto-plastic large deflection numerical solutions. The former was concerned with plates stiffened by T-bars while the latter used bulb flats in one case and trapezoidal sections in a second case.

Details of the plate panels are given in Table 7.1. For the odd-numbered plates JF1, JE3, …… of Jackson and Frieze, the yield stress $\sigma_y$ is 353 N/mm$^2$ and the elastic modulus $E$ is 207600 N/mm$^2$; the corresponding values for the even-numbered plates JF2, JF4, …… are 399 N/mm$^2$ and 217800 N/mm$^2$. For Zhang’s plates ZA and ZB, the yield stress averaged 301 N/mm$^2$ and the elastic modulus 204500 N/mm$^2$. $w_0$ is the initial central deflection of the tested panel and $\sigma_{RL}$, $\sigma_{RT}$ are the longitudinal and transverse welding residual stresses.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>b (mm)</th>
<th>a/b</th>
<th>$b/t$</th>
<th>B (mm)</th>
<th>$w_0$ (mm)</th>
<th>$\sigma_{RL}$ (N/mm$^2$)</th>
<th>$\sigma_{RT}$ (N/mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JF1</td>
<td>450</td>
<td>1</td>
<td>62.1</td>
<td>125</td>
<td>0.68</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF2</td>
<td>450</td>
<td>1</td>
<td>63.6</td>
<td>125</td>
<td>2.90</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF3</td>
<td>450</td>
<td>1</td>
<td>62.1</td>
<td>75</td>
<td>2.60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF4</td>
<td>450</td>
<td>1</td>
<td>63.6</td>
<td>75</td>
<td>3.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF5</td>
<td>225</td>
<td>2</td>
<td>31.2</td>
<td>125</td>
<td>0.80</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF6</td>
<td>225</td>
<td>2</td>
<td>31.9</td>
<td>125</td>
<td>1.40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF7</td>
<td>225</td>
<td>2</td>
<td>31.2</td>
<td>75</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF8</td>
<td>225</td>
<td>2</td>
<td>31.9</td>
<td>75</td>
<td>0.70</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>JF9</td>
<td>450</td>
<td>2</td>
<td>61.4</td>
<td>125</td>
<td>0.10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF10</td>
<td>450</td>
<td>2</td>
<td>63.8</td>
<td>125</td>
<td>1.30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF11</td>
<td>450</td>
<td>2</td>
<td>61.2</td>
<td>75</td>
<td>1.40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF12</td>
<td>450</td>
<td>2</td>
<td>64.1</td>
<td>75</td>
<td>4.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF13</td>
<td>225</td>
<td>4</td>
<td>31.2</td>
<td>125</td>
<td>0.70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF14</td>
<td>225</td>
<td>4</td>
<td>31.9</td>
<td>125</td>
<td>0.60</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>JF15</td>
<td>225</td>
<td>4</td>
<td>31.2</td>
<td>75</td>
<td>0.40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF16</td>
<td>225</td>
<td>4</td>
<td>31.9</td>
<td>75</td>
<td>1.00</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>JF17</td>
<td>450</td>
<td>4</td>
<td>61.9</td>
<td>125</td>
<td>3.10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF18</td>
<td>450</td>
<td>4</td>
<td>63.6</td>
<td>125</td>
<td>0.80</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JF19</td>
<td>450</td>
<td>4</td>
<td>62.3</td>
<td>75</td>
<td>2.90</td>
<td>105</td>
<td>20</td>
</tr>
<tr>
<td>JF20</td>
<td>450</td>
<td>4</td>
<td>63.8</td>
<td>75</td>
<td>1.60</td>
<td>65</td>
<td>20</td>
</tr>
<tr>
<td>JF21</td>
<td>225</td>
<td>8</td>
<td>31.1</td>
<td>125</td>
<td>2.40</td>
<td>120</td>
<td>20</td>
</tr>
<tr>
<td>JF22</td>
<td>225</td>
<td>8</td>
<td>31.9</td>
<td>125</td>
<td>0.11</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>JF23</td>
<td>225</td>
<td>8</td>
<td>31.1</td>
<td>75</td>
<td>2.80</td>
<td>120</td>
<td>20</td>
</tr>
<tr>
<td>JF24</td>
<td>225</td>
<td>8</td>
<td>31.9</td>
<td>75</td>
<td>0.20</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>ZA</td>
<td>475</td>
<td>3.6</td>
<td>38.3</td>
<td>150</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ZB</td>
<td>694</td>
<td>2.6</td>
<td>56.0</td>
<td>150</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The results of Jackson and Frieze were presented primarily in the form of normalised load versus normalised total deflections and normalised permanent set curves as discussed below. Zhang presented similar results but also an extensive range of strains and displacements from the considerable number of deflection transducers and strain gauges deployed on the models. The numerical results were also presented in detail.

7.2 PARAMETERS AFFECTING PLATE BEHAVIOUR

7.2.1 Basic aspects of behaviour

Figure 7.1 presents a typical experimental load-deflection plot for a plate panel of a stiffened steel grillage subjected to a central simulated wheel load. The deflection is normal to the deck, that is, out-of-plane, and is measured at the centre of the panel.

The figure has been extracted from the paper by Jackson and Frieze and relates to model no. JF4. Each load increment and decrement is numbered sequentially. It can thus be seen that initially the load is increased, and then decreased in order to establish the permanent set. The load is then increased to a higher value than the previous maximum, and then removed to determine the next increment of permanent set. This process is repeated a sufficient number of times to enable the load-permanent set relationship to be established. For this panel, it can be seen that eleven unloading sequences were used.

An examination of the first loading path indicates that the initial response is elastic. The numerical studies of Jackson and Frieze indicated permanent set occurred when yielding initiated under the load. The same conclusion was reached by Hughes [12] who examined analytically the distribution of bending moments as the ratio of load diameter to plate width varied from approximately zero (i.e. point load) to the uniform load condition.
Beyond the ‘knee’ in the primary load path, the load versus deflection response is approximately linear as demonstrated in Figure 7.2, which presents some of the complementary numerical results of Jackson and Frieze. The results relate to panels having configurations similar to those of model nos JF5, JF13 and JF21. The load parameter $C_p$ is a normalised measure of the patch load $P$ and is given by $C_p = PE/(b\sigma_y)^2$ while $C_d = d/\beta t$ is a normalised total deflection in which $d$ is the total central deflection and $\beta = (b/t)(\sigma_y/E)^{0.5}$ is a normalised plate slenderness. Hughes also concludes that the response beyond the knee is linear particularly in the uniform loading case.

Upon each reloading, it is seen in Figure 7.1 that the unloading path is retraced until the primary loading path is encountered. These unloading and reloading paths are entirely elastic. Once the primary path is re-encountered, the response continues to follow this path independent of the extent and sequence of unloading and reloading. This does not hold true if the unloading is reversed to the extent that yield occurs but of opposite sign.

In the following sub-sections, each of the parameters affecting response is examined to identify qualitatively its influence on response.

### 7.2.2 Aspect ratio $a/b$

The effect of aspect ratio was examined by Jackson and Frieze both experimentally and numerically. No discernible trend with aspect ratio was noted when the full deck layout was considered. This was demonstrated specifically through consideration of the permanent set under load of six panels of identical description except for differences in length, which realised aspect ratios of 1, 2 and 4.
7.2.3 Plate slenderness

Plate slenderness is described by the width to thickness ratio $b/t$ or its normalised equivalent $\beta$ (this is denoted $C_b$ by Jackson and Frieze). The most obvious influence of this is the effect on deflections and thus on the onset of permanent set. The greater the slenderness, the larger the deflections which leads to the earlier mobilisation of membrane tension. The latter gradually replaces bending as the prime action resisting lateral loading as deflections increase.

These effects are clearly seen by comparing the load-deflection results in Figure 7.3. In (a), the results relate to panels of $b/t \approx 31$ ($\beta \approx 1.3$) and in (b) to panels of $b/t \approx 63$ ($\beta \approx 2.6$). In (a) it is seen that the more stocky panels do not demonstrate significant permanent set until $C_p \approx 2$ in the case of $b/B = 3.0$ or $C_p \approx 4$ when $b/B = 1.8$. The corresponding values for the slender panels are $C_p \approx 0.25$ when $b/B = 6.0$ and $C_p \approx 0.5$ when $b/B = 3.6$.

7.2.4 Material properties

Because yield stress and elastic modulus are involved in the non-dimensional description of slenderness, they play a similar role to width and thickness in their effect on panel deflections and permanent set. However, the material properties appear in the relevant expression to the power 0.5 so that changes in the properties must be correspondingly greater than those of the variables $b$ and $t$ in order to realise the same effect.

![Figure 7.3](image)

Load-total permanent set plots for models JF1 to JF24

7.2.5 Plate width to patch width ratio

An examination of how the bending moments vary at the centre and at the edges of a built-in beam indicates there is no simple relationship between such moments and the ratio of plate width to patch width. However, it is clear that both moments increase as the ratio increases. As the moment at the plate centre is generally the larger, yielding and therefore permanent set will occur earlier as the patch width decreases. This is demonstrated in Figure 7.4 which presents numerical and experimental results that show the variation of normalised load with slenderness ratio $\beta$ for four $b/B$ ratios. The results relate to a normalised permanent set of 0.1 and clearly demonstrate the reduction in load that occurs as this ratio increase.
7.2.6 Plate initial distortions

As seen in Table 7.1, both positive (in the direction of loading) and negative plate initial deflections occurred in the models. The normalised initial set \( w_0/\beta t \) ranged from -0.297 (JF23) to 0.204 (JF12), the largest value corresponding to b/80. The experimental results demonstrated that distortions in the direction of loading led to stiffer load-deflection responses: this was also confirmed numerically. The effect of initial distortions appears to be secondary compared with that of the parameters considered above.

7.2.7 Welding residual stresses

There was insufficient evidence from the experimental results to draw in clear conclusions concerning the effect on response of welding residual stresses. A significant effect was however found in the limited numerical study reported by Jackson and Frieze, the larger the longitudinal residual stress, the lower the stiffness under lateral loading. A level of residual stress equal to 25% of yield stress was concluded to be sufficient to account for most of the detrimental effects of this variable.

7.3 PLATE CLOSED-FORM SOLUTIONS

7.3.1 Available solutions

In Section 5, a number of closed-form solutions were identified. Three of these originated from the Classification Societies of Det Norske Veritas, Germanischer Lloyd, and Lloyd’s Register of Shipping: relevant extracts of each of these procedures are presented in Appendices D to F. General technical information was derived from the paper by Viner [13] concerning the LRS procedure. However, for none of the procedures was any background report apparently available.
Two other closed-form solutions identified were those of Jackson and Frieze, and Hughes. The former was presented in graphical form based on interpolation and extrapolation of the combined set of experimental and numerical results obtained in the study. The latter was reported in mathematical form and was based on a multiple-regression fit to the results of Jackson and Frieze: the equation is presented in Section 5.4.

### 7.3.2 Example calculations

Example calculations for each of the procedures considered above are now presented. In determining the Classification Societies formulation capacities, these are calculated in the absence of any load factors in order to be compatible with the experimental results. On the grounds that none of the formulations has any specified formal basis, it is assumed in presenting the comparisons that none allows any permanent set.

Table 7.2 list the maximum loads (in normalised form) sustained by the models prior to the onset of any permanent set. In identifying the experimental value, this was derived as the point of intersection of the two ‘linear’ segments of the curves. This was selected as it was judged to be relatively well defined compared with the true point of departure from linearity while also seeming to be the closest approximation to the same point as determined from Hughes’ formulation.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Expt.</th>
<th>Hughes</th>
<th>DNV</th>
<th>GL</th>
<th>LRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>JF1</td>
<td>0.62</td>
<td>0.55</td>
<td>0.39</td>
<td>0.42</td>
<td>0.41</td>
</tr>
<tr>
<td>JF2</td>
<td>0.55</td>
<td>0.48</td>
<td>0.35</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>JF3</td>
<td>0.35</td>
<td>0.33</td>
<td>0.31</td>
<td>0.30</td>
<td>0.28</td>
</tr>
<tr>
<td>JF4</td>
<td>0.29</td>
<td>0.29</td>
<td>0.28</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>JF5</td>
<td>≈4.50</td>
<td>4.33</td>
<td>2.00</td>
<td>2.25</td>
<td>2.79</td>
</tr>
<tr>
<td>JF6</td>
<td>≈4.00</td>
<td>3.84</td>
<td>1.78</td>
<td>2.00</td>
<td>2.49</td>
</tr>
<tr>
<td>JF7</td>
<td>1.80</td>
<td>2.60</td>
<td>1.32</td>
<td>1.47</td>
<td>1.59</td>
</tr>
<tr>
<td>JF8</td>
<td>2.02</td>
<td>2.30</td>
<td>1.17</td>
<td>1.30</td>
<td>1.42</td>
</tr>
<tr>
<td>JF9</td>
<td>0.45</td>
<td>0.56</td>
<td>0.31</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>JF10</td>
<td>0.47</td>
<td>0.48</td>
<td>0.26</td>
<td>0.28</td>
<td>0.30</td>
</tr>
<tr>
<td>JF11</td>
<td>0.27</td>
<td>0.34</td>
<td>0.24</td>
<td>0.25</td>
<td>0.26</td>
</tr>
<tr>
<td>JF12</td>
<td>0.27</td>
<td>0.29</td>
<td>0.21</td>
<td>0.21</td>
<td>0.22</td>
</tr>
<tr>
<td>JF13</td>
<td>≈4.20</td>
<td>4.33</td>
<td>1.90</td>
<td>2.15</td>
<td>2.70</td>
</tr>
<tr>
<td>JF14</td>
<td>≈3.65</td>
<td>3.84</td>
<td>1.69</td>
<td>1.91</td>
<td>2.41</td>
</tr>
<tr>
<td>JF15</td>
<td>2.20</td>
<td>2.60</td>
<td>1.25</td>
<td>1.33</td>
<td>1.59</td>
</tr>
<tr>
<td>JF16</td>
<td>1.56</td>
<td>2.30</td>
<td>1.11</td>
<td>1.18</td>
<td>1.42</td>
</tr>
<tr>
<td>JF17</td>
<td>0.54</td>
<td>0.55</td>
<td>0.29</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td>JF18</td>
<td>0.46</td>
<td>0.48</td>
<td>0.25</td>
<td>0.26</td>
<td>0.30</td>
</tr>
<tr>
<td>JF19</td>
<td>0.25</td>
<td>0.33</td>
<td>0.22</td>
<td>0.22</td>
<td>0.26</td>
</tr>
<tr>
<td>JF20</td>
<td>0.28</td>
<td>0.29</td>
<td>0.20</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
<td>JF21</td>
<td>≈4.00</td>
<td>4.35</td>
<td>1.92</td>
<td>2.16</td>
<td>2.70</td>
</tr>
<tr>
<td>JF22</td>
<td>≈3.60</td>
<td>3.84</td>
<td>1.69</td>
<td>1.91</td>
<td>2.41</td>
</tr>
<tr>
<td>JF23</td>
<td>2.46</td>
<td>2.61</td>
<td>1.26</td>
<td>1.34</td>
<td>1.59</td>
</tr>
<tr>
<td>JF24</td>
<td>2.10</td>
<td>2.30</td>
<td>1.11</td>
<td>1.18</td>
<td>1.42</td>
</tr>
<tr>
<td>ZA</td>
<td>1.06</td>
<td>1.44</td>
<td>0.81</td>
<td>0.85</td>
<td>1.04</td>
</tr>
<tr>
<td>ZB</td>
<td>0.26</td>
<td>0.46</td>
<td>0.32</td>
<td>0.33</td>
<td>0.40</td>
</tr>
</tbody>
</table>
The presented Classification Society formulations are in the usual format for design, that is, given the load, determine the required plating thickness. In the current circumstances, the thickness is already known. Thus, for the load capacities listed in Table 7.2, the sequence of calculations to realise these was the reverse of that of a normal design assessment. That is, the thickness values listed in Table 7.1 were used to calculate the loads presented in Table 7.2.

To avoid confusion, it is appropriate to present calculations in the normal manner. Therefore, the loads listed in Table 7.2 will be used to determine the thicknesses, which can be compared with those in Table 7.1. In conducting the calculations, no account is taken of corrosion allowances.

Details of the calculations are given below. As indicated, they relate to the assessments without load factors. The calculations apply to model JF1. For this, a common calculation is the evaluation of the load \( P \) given the normalised load in Table 7.2, \( C_p = PE/(b\sigma_y)^2 \). For JF1, \( E = 207600 \text{ N/mm}^2, b = 450 \text{ mm} \) and \( \sigma_y = 353 \text{ N/mm}^2 \). Thus \( P = 121.6C_p \text{ kN} \). The plate thickness is 7.25 mm.

**Det Norske Veritas:**

The DNV requirements are presented in Appendix D. Referring to Clause C 201, the governing equation to determine the thickness \( t \) is \( t = 77.4 \frac{k_d}{(k_wbsp/m^2)^{0.5}} \). The input parameters are:

- pressure \( p = P/ab \): from Table 7.2 \( C_p = 0.39 \) (actually 0.392) so \( P = 121.6C_p = 47.67 \text{ kN} \) and \( p = 47.67/(0.25 \times 0.125) = 1525 \text{ kN/m}^2 \)
- coefficient \( k_d = 1.1 - 0.25 s/l = 1.1 - 0.25 \times 0.45/0.45 = 0.85 \)
- coefficient \( k_w = 1.3 - 4.2/(a/s + 1.8)^2 = 1.3 - 4.2/(0.25/0.45 + 1.8)^2 = 0.54 \)
- coefficient \( m = 38/[(b/s)^2 - 4.7b/s + 6.5] = 38/[(0.125/0.45)^2 - 4.7(0.125)/0.45 + 6.5] = 7.208 \)
- material factor \( f_1 \): taken as 1.5 so \( \sigma = \sigma_y \times 1.51 = 353 \times 1.51 = 533. \)

The required plate thickness \( t = 77.4 \times 0.85 \times 0.54 \times 0.125 \times 0.45 \times 1525/(7.208 \times 533)^{0.5} = 7.224 \). The supplied thickness is 7.25 mm.

**Germanischer Lloyd:**

The GL requirements are presented in Appendix E. Referring to Clause 3.3, the governing equation to determine the thickness \( t \) is \( t = c(F \times 235/ReH)^{0.5} \). The input parameters are:

- load \( F \): from Table 7.2 \( C_p = 0.42 \) (actually 0.422) so \( F = 121.6C_p = 51.32 \text{ kN} \)
- coefficient \( c \): for \( \alpha = A/a.b = 0.25 \times 0.125/(0.45 \times 0.45) = 0.154 \) and \( b/a = 0.45/0.45 = 1 \), \( c = 1.90 - [\alpha (3.5 - 4.4\alpha)]^{0.5} = 1.90 - [0.154 \times (3.5 - 4.4\times0.154)]^{0.5} = 1.241 \)
- \( ReH = 353 \).

The required plate thickness \( t = 1.241 \times (51.32 \times 235/353)^{0.5} = 7.254 \). The supplied thickness is 7.25 mm.

**Lloyd’s Register of Shipping:**

In applying the LRS approach, the constitutive parts of the load factor needs careful consideration. In the equation as presented, the notional factor is 2.5 - see Appendix F. Also included in the equation is a coefficient \( y \), described as a location factor and normally taking the value 0.6. Unless this factor is amalgamated with the 2.5 factor to provide a load factor of 1.5, then the requirements for helicopter landing areas are not consistent with those for other decks loaded by wheeled vehicles. Thus, in the evaluation of the LRS unfactored plate panel load capacity, \( y \) is ignored (i.e. taken as unity). For the factored equivalent, the amalgamated load factor of 1.5 is used. This was noted in Table 4.1 as the appropriate factor.

Referring to Clause 5.4.1, (see Appendix F) the governing equation to determine the thickness \( t \) is \( t = \alpha s/1000(k)^{0.5} \).
The input parameters are:
- **load** $P_w$: from Table 7.2 $C_p = 0.41$ (actually 0.405) so $P_w = 121.6 C_p = 49.25 \text{kN} = 5.020 t$
- coefficient $\phi_1 = (2v + 1.1s)/(u + 1.1s) = (2 \times 125 + 1.1 \times 450)/(250 + 1.1 \times 450) = 1.0$
- coefficient $\phi_2$: for $a \geq u > (a - s) = 450 \geq 250 > (450 - 450), \phi_2 = 1/[1.3 - 0.3(a-u)/s]$
  \[ = 1/[1.3 - 0.3(450-250)/450] = 0.857 \]
- coefficient $\phi_3$: for $v < s = 125 < 450, \phi_3 = 1.0$
- coefficient $f$: take as 1.0
- coefficient $\gamma$: nominally equal to 0.6 but this parameter has been taken as part of the load factor as discussed above so, here, its value is taken as 1.0
- coefficient $P_1 = \phi_1 \phi_2 \phi_3 f \gamma P_w = 1.0 \times 0.857 \times 1.0 \times 1.0 \times 5.020 = 4.302$
- coefficient $k = 245/\sigma_y = 245/353 = 0.694$
- coefficient $b = \log (P_1 k^2 10^7/s^2) = \log (4.302 \times 0.694^2 \times 10^7/450^2) = 2.010$
- coefficient $\alpha$: from Fig. 2.1.1 for $\beta = 2.010$ and $v/s = 125/450 = 0.278$, $\alpha = 13.4$

The required plate thickness $t = 13.4 \times 450/1000/0.694^{0.5} = 7.238$. The supplied thickness is 7.25 mm.

**Hughes’ empirical equation:**

In contrast with the Classification Society formulations, this is an assessment rather than a design procedure in that the load capability is determined given the geometries of the plate and the patch, the material properties, and the magnitude of the permanent set. Consideration of load factors is not required since none is contained within the expression.

Hughes’ empirical equation is presented in Section 5.4. When no permanent set is to be allowed, the governing equation to determine the load capacity is $C_p = \phi 10.45/\gamma$. The input parameters are:
- coefficient $\phi = 1 - 0.8[ef/(e^2 + f^2)^2] = 1 - 0.8[250 \times 125/(250^2 + 125^2)]^2 = 0.872$
- coefficient $\beta = b/t (\sigma_y/E)^{0.5} = 450/7.25 (353/207600)^{0.5} = 2.559$
- coefficient $\mu = (ef)^{0.5}/b = (250 \times 125)^{0.5}/450 = 0.393$.

The required load capacity $P = 0.872 \times 10.45 \times 0.393/2.559^2 = 0.547$ as given in Table 7.2. The applied load is 0.62, both in normalised form.

### 7.4 FIRST PRINCIPLE PROCEDURES

#### 7.4.1 Plate strip solutions

First principle estimates of load capacities can be based on a plate strip solution. This assumes both the plate panel and the load to be infinitely long which reduces the analysis from three-to-two-dimensions. This makes the analysis tractable to ‘hand-calculations’. This approach appears to be justified on the basis that the test results of Jackson and Friese found the deflections and permanent set to be independent of plate aspect ratio. However, the considered test results are restricted to loads of aspect ratio two, the longer side oriented in the direction of the longer plate dimension. Discussion to the paper presented further test results. These indicated, without full details, that plates with loads of aspect ratio 1.0 are less stiff than those with loads of other aspect ratios. Indications were given that plates with loads of aspect ratio 2.0 and 0.5 had similar stiffnesses. The comparisons to be presented will therefore only strictly be representative of rectangular shaped loads.

#### 7.4.2 Example calculations

Details of the calculations are presented below. They are based on two criteria. The first assumes the plating remains elastic with the maximum stress limited to yield. The second allows the full plastic hinge capacity to be realised. The load is assumed to be central on a plate and allowance is made for the influence of adjacent spans on the flexural response of the
considered panel. In-plane or membrane stresses are ignored as these require non-linear numerical analysis procedures for their evaluation.

First yield

For a first yield analysis, continuity over three spans is adequate to define the bending moment distribution associated with a patch load centred on the middle span. The configuration is shown in Figure 7.5. The simply supported bending moment diagram is illustrated. The presented equation for the maximum moment $M$ is seen to converge to the relevant expressions for a load distributed over the length of the centre span, so that $B = b$ gives $M = Pb/8$, and for a concentrated load when $B = 0$ giving $M = Pb/4$. Taking account of continuity over the internal supports leads to support moments of $M_s = 0.4M$ and $M_s = 0.3M$ for the uniformly and point loaded cases respectively.

Assuming the support moment to vary linearly between the two extremes of a uniformly and a point loaded beam condition, the support moment can be generalised as $M_s = M(0.3 + 0.1B/b)$. The centre moment is always larger than the support moment and is thus the location of first yield: it is given by $M_c = M - M_s = M(1 - 0.3 - 0.1B/b) = M(0.7 - 0.1B/b)$.

The transverse bending stress at the centre $g_1(s) = M_c/Z$ where $Z = t^2/6$ is the section modulus for a plate strip. For a plate strip it follows that the longitudinal stress $g_1 = \nu \sigma_1$ where $\nu$ is Poisson’s ratio which has the value 0.3 for steel.

Yield occurs when the Mises-Henky equivalent stress $\sigma_\epsilon$ equals the uniaxial tensile yield stress. The equivalent stress is given by $\sigma_\epsilon = (\sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2)^{0.5}$. Substituting for $\sigma_\epsilon$, this simplifies to $\sigma_\epsilon = 0.89\sigma_y$. Yield occurs when $\sigma_1 = \sigma_2/0.89 = \sigma_y/0.89 \approx \sigma_y/9.8$. The corresponding internal moment $M_c = Z \sigma_1 = t^2/6 \sigma_y/9.8 = \sigma_y t^2/3.16$.

Substituting for $M$ from Figure 7.5 and equating the internal and external moments $\sigma_y t^2/3.16 = P/4 (b - B/2)(0.7 - 0.1B/b)$ which can be rearranged to give $P = 3/4 \sigma_y (t^2/b)/(1-0.5B/b)/(0.7-0.1B/b)$ N/mm. For model JF1, $P = (3/4) x 353 x 7.25^2/450/(1-0.5x125/450)/(0.7-0.1x125/450) = 53.4$ N/mm. For a patch length of 250mm, the total load is $250 P = 13,360$N. In normalised form the total load $C_P = PE/(b\sigma_y)^2 = 13,360 x 207,600/(450 x 353)^2 = 0.110$: this is listed in column 3 of Table 7.4.
Plastic hinge capacity

The plastic hinge capacity is calculated on the basis that hinges form at each end of the loaded span and at the centre where the moment is maximum. The plastic section modulus for a plate strip is \( t^2/4 \) so the plastic moment \( M_p = \frac{t^2}{4} \sigma_y \), where \( \sigma_y = 9/32 \) which is 50% greater than the first yield moment. From the bending moment diagram in Figure 7.6, it is seen that \( 2M_p = M \), the magnitude of the simply supported bending moment. The associated load \( P_p \) is found from \( 2M_p = P_p/4 (b - B/2) \) so that \( P_p = 8M_p/(b - B/2) \). Substituting for \( M_p \), \( P_p = 9/4 \sigma_y t^2/(b - B/2) \) N/mm.

For model JF1, \( P_p = (9/4) \times 353 \times 7.25^2/(450-125/2) = 107.7 \) N/mm. For a patch length of 250 mm the total load 26,930 N, or in normalised form \( C_p = 26,930 \times 207.600/(450 \times 353)^2 = 0.221 \), which is listed in column 5 of Table 7.4.

7.5 PLATE PREDICTIONS VERSUS TEST RESULTS

7.5.1 Closed-form solutions

Detailed example calculations were presented above for each of the identified procedures for one experimental plate. Here, the experimental results and the predictions of the procedures are compared in tabular and graphical form.

Table 7.2 lists the maximum test load capacity corresponding to zero permanent set together with the corresponding value from Hughes’ empirical equation and the four Classification Society formulations. It is seen that Hughes’ approach over-estimates the test values thereby allowing permanent sets to occur. The DNV, GL and LRS formulations very infrequently allow a small set to arise.

These differences are clearly illustrated in Appendix G where the graphical comparisons between the test results and the predictions are presented. For these, both the experimental results and the predictions of Hughes’ formulation are presented in curvilinear form, the former having been extracted from Figure 7.3 for finite permanent sets. Hughes’ load-deflection curves are seen to be skew with respect to the test curves. They indicate that the deflections grow at a faster rate than found in practice while nearly always over-estimating the capacity at which permanent set initially occurs.
For design, load factors are applied. These are listed in Tables 4.1 and 4.2 for ‘landing’ and ‘at rest’ conditions. According to guidance and CAP 437, the former should be subdivided into heavy and emergency landings which attract different factors. As noted above, feedback from designers and operators indicated that the ‘heavy’ requirement probably never governs.

Table 7.3 lists the factored design loads for the three Classification Society formulations: the relevant factors are listed in each column heading. Also listed are the experimental results factored in two ways. Firstly, the CAP and HSE emergency landing factor of 2.5 is applied. Secondly, the additional ‘deck response factor’ of 1.3 is included. These two sets of values are presented to provide indicative loads beyond which permanent set can be expected to occur should the load exceed its design value by a proportion indicated by the load factor. Permanent set would occur should any of the factored values exceed the unfactored test results of Table 7.2. In no case does this happen.

### Table 7.3
Comparison between normalised experimental loads at zero permanent set and factored design loads

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Expt. + 2.5</th>
<th>Expt. + (2.5x1.3)</th>
<th>DNV + 2.0</th>
<th>GL + 1.5</th>
<th>LRS + 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>JF1</td>
<td>0.25</td>
<td>0.19</td>
<td>0.20</td>
<td>0.28</td>
<td>0.27</td>
</tr>
<tr>
<td>JF2</td>
<td>0.22</td>
<td>0.17</td>
<td>0.17</td>
<td>0.25</td>
<td>0.23</td>
</tr>
<tr>
<td>JF3</td>
<td>0.14</td>
<td>0.11</td>
<td>0.16</td>
<td>0.20</td>
<td>0.19</td>
</tr>
<tr>
<td>JF4</td>
<td>0.12</td>
<td>0.09</td>
<td>0.14</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>JF5</td>
<td>1.80</td>
<td>1.38</td>
<td>1.00</td>
<td>1.50</td>
<td>1.86</td>
</tr>
<tr>
<td>JF6</td>
<td>1.60</td>
<td>1.23</td>
<td>0.89</td>
<td>1.33</td>
<td>1.66</td>
</tr>
<tr>
<td>JF7</td>
<td>0.72</td>
<td>0.55</td>
<td>0.66</td>
<td>0.98</td>
<td>1.06</td>
</tr>
<tr>
<td>JF8</td>
<td>0.81</td>
<td>0.62</td>
<td>0.59</td>
<td>0.87</td>
<td>0.94</td>
</tr>
<tr>
<td>JF9</td>
<td>0.18</td>
<td>0.14</td>
<td>0.15</td>
<td>0.22</td>
<td>0.24</td>
</tr>
<tr>
<td>JF10</td>
<td>0.19</td>
<td>0.14</td>
<td>0.13</td>
<td>0.19</td>
<td>0.20</td>
</tr>
<tr>
<td>JF11</td>
<td>0.11</td>
<td>0.08</td>
<td>0.12</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>JF12</td>
<td>0.11</td>
<td>0.08</td>
<td>0.10</td>
<td>0.14</td>
<td>0.15</td>
</tr>
<tr>
<td>JF13</td>
<td>1.68</td>
<td>1.29</td>
<td>0.95</td>
<td>1.43</td>
<td>1.80</td>
</tr>
<tr>
<td>JF14</td>
<td>1.46</td>
<td>1.12</td>
<td>0.85</td>
<td>1.27</td>
<td>1.60</td>
</tr>
<tr>
<td>JF15</td>
<td>0.88</td>
<td>0.68</td>
<td>0.63</td>
<td>0.89</td>
<td>1.06</td>
</tr>
<tr>
<td>JF16</td>
<td>0.62</td>
<td>0.48</td>
<td>0.56</td>
<td>0.79</td>
<td>0.94</td>
</tr>
<tr>
<td>JF17</td>
<td>0.22</td>
<td>0.17</td>
<td>0.14</td>
<td>0.20</td>
<td>0.23</td>
</tr>
<tr>
<td>JF18</td>
<td>0.18</td>
<td>0.14</td>
<td>0.13</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>JF19</td>
<td>0.10</td>
<td>0.08</td>
<td>0.11</td>
<td>0.15</td>
<td>0.17</td>
</tr>
<tr>
<td>JF20</td>
<td>0.11</td>
<td>0.09</td>
<td>0.10</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>JF21</td>
<td>1.60</td>
<td>1.23</td>
<td>0.96</td>
<td>1.44</td>
<td>1.80</td>
</tr>
<tr>
<td>JF22</td>
<td>1.44</td>
<td>1.11</td>
<td>0.85</td>
<td>1.27</td>
<td>1.60</td>
</tr>
<tr>
<td>JF23</td>
<td>0.98</td>
<td>0.76</td>
<td>0.63</td>
<td>0.89</td>
<td>1.06</td>
</tr>
<tr>
<td>JF24</td>
<td>0.84</td>
<td>0.65</td>
<td>0.56</td>
<td>0.79</td>
<td>0.94</td>
</tr>
<tr>
<td>ZA</td>
<td>0.42</td>
<td>0.33</td>
<td>0.41</td>
<td>0.57</td>
<td>0.69</td>
</tr>
<tr>
<td>ZB</td>
<td>0.10</td>
<td>0.08</td>
<td>0.16</td>
<td>0.22</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Comparison of the three Classification Society design loads in Table 7.3 indicates that the LRS estimates are generally the largest, followed by GL and DNV. The order is generally unchanged compared with the unfactored values in Table 7.2 except that the GL capacities now always exceed those of DNV whereas previously the reverse was sometimes the case.
Considering that none of the Classification Society formulations require the use of a deck response factor, the comparison of design values in Table 7.3 suggests the imposition of this factor will lead to significant penalties should it not really be required. There is evidence in the operators’ specifications that this factor is applied whether relevant or not.

### 7.5.2 Plate strip solutions

The results of the calculations for each model are presented in Table 7.4 in normalised form for both the first yield and the full plastic hinge capacities. Both are then divided into the maximum test load corresponding to zero permanent set to provide a means of measuring the suitability of the approach for design. The statistics of these two sets of ratios are evaluated and listed at the bottom of the relevant columns in terms of mean, standard deviation and coefficient of variation (COV).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>JF1</td>
<td>3.60</td>
<td>0.110</td>
<td>5.650</td>
<td>0.221</td>
<td>2.800</td>
<td>(1, 63)</td>
<td>(1)</td>
</tr>
<tr>
<td>JF2</td>
<td>3.60</td>
<td>0.097</td>
<td>5.660</td>
<td>0.196</td>
<td>2.810</td>
<td>2.760</td>
<td>2.760</td>
</tr>
<tr>
<td>JF3</td>
<td>6.00</td>
<td>0.061</td>
<td>5.750</td>
<td>0.125</td>
<td>2.800</td>
<td>0.089</td>
<td>0.089</td>
</tr>
<tr>
<td>JF4</td>
<td>6.00</td>
<td>0.054</td>
<td>5.380</td>
<td>0.110</td>
<td>2.630</td>
<td>0.032</td>
<td>0.032</td>
</tr>
<tr>
<td>JF5</td>
<td>1.80</td>
<td>1.082</td>
<td>4.160</td>
<td>2.091</td>
<td>2.150</td>
<td>(2, 31)</td>
<td></td>
</tr>
<tr>
<td>JF6</td>
<td>1.80</td>
<td>0.961</td>
<td>4.160</td>
<td>1.857</td>
<td>2.150</td>
<td>2.013</td>
<td></td>
</tr>
<tr>
<td>JF7</td>
<td>3.00</td>
<td>0.544</td>
<td>3.310</td>
<td>1.088</td>
<td>1.660</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td>JF8</td>
<td>3.00</td>
<td>0.483</td>
<td>4.180</td>
<td>0.966</td>
<td>2.090</td>
<td>0.119</td>
<td></td>
</tr>
<tr>
<td>JF9</td>
<td>3.60</td>
<td>0.112</td>
<td>4.010</td>
<td>0.226</td>
<td>1.990</td>
<td>(2, 63)</td>
<td>(2)</td>
</tr>
<tr>
<td>JF10</td>
<td>3.60</td>
<td>0.097</td>
<td>4.870</td>
<td>0.195</td>
<td>2.410</td>
<td>2.246</td>
<td>2.075</td>
</tr>
<tr>
<td>JF11</td>
<td>6.00</td>
<td>0.063</td>
<td>4.310</td>
<td>0.128</td>
<td>2.100</td>
<td>0.240</td>
<td>0.290</td>
</tr>
<tr>
<td>JF12</td>
<td>6.00</td>
<td>0.053</td>
<td>5.090</td>
<td>0.109</td>
<td>2.480</td>
<td>0.107</td>
<td>0.140</td>
</tr>
<tr>
<td>JF13</td>
<td>1.80</td>
<td>1.082</td>
<td>3.880</td>
<td>2.091</td>
<td>2.010</td>
<td>(4, 31)</td>
<td></td>
</tr>
<tr>
<td>JF14</td>
<td>1.80</td>
<td>0.961</td>
<td>3.800</td>
<td>1.857</td>
<td>1.970</td>
<td>1.903</td>
<td></td>
</tr>
<tr>
<td>JF15</td>
<td>3.00</td>
<td>0.544</td>
<td>4.050</td>
<td>1.088</td>
<td>2.020</td>
<td>0.193</td>
<td></td>
</tr>
<tr>
<td>JF16</td>
<td>3.00</td>
<td>0.483</td>
<td>3.230</td>
<td>0.966</td>
<td>1.620</td>
<td>0.102</td>
<td></td>
</tr>
<tr>
<td>JF17</td>
<td>3.60</td>
<td>0.110</td>
<td>4.890</td>
<td>0.223</td>
<td>2.420</td>
<td>(4, 63)</td>
<td>(4)</td>
</tr>
<tr>
<td>JF18</td>
<td>3.60</td>
<td>0.097</td>
<td>4.730</td>
<td>0.196</td>
<td>2.350</td>
<td>2.335</td>
<td>2.110</td>
</tr>
<tr>
<td>JF19</td>
<td>6.00</td>
<td>0.060</td>
<td>4.130</td>
<td>0.124</td>
<td>2.020</td>
<td>0.228</td>
<td>0.284</td>
</tr>
<tr>
<td>JF20</td>
<td>6.00</td>
<td>0.054</td>
<td>5.230</td>
<td>0.110</td>
<td>2.550</td>
<td>0.098</td>
<td>0.135</td>
</tr>
<tr>
<td>JF21</td>
<td>1.80</td>
<td>1.089</td>
<td>3.670</td>
<td>2.105</td>
<td>1.900</td>
<td>(8, 31)</td>
<td>(8)</td>
</tr>
<tr>
<td>JF22</td>
<td>1.80</td>
<td>0.961</td>
<td>3.750</td>
<td>1.857</td>
<td>1.940</td>
<td>2.065</td>
<td>2.065</td>
</tr>
<tr>
<td>JF23</td>
<td>3.00</td>
<td>0.547</td>
<td>4.490</td>
<td>1.095</td>
<td>2.250</td>
<td>0.172</td>
<td>0.172</td>
</tr>
<tr>
<td>JF24</td>
<td>3.00</td>
<td>0.483</td>
<td>4.350</td>
<td>0.966</td>
<td>2.170</td>
<td>0.083</td>
<td>0.083</td>
</tr>
<tr>
<td>ZA</td>
<td>3.17</td>
<td>0.260</td>
<td>4.080</td>
<td>0.521</td>
<td>2.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZB</td>
<td>4.63</td>
<td>0.077</td>
<td>3.330</td>
<td>0.158</td>
<td>1.630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>4.390</td>
<td>2.191</td>
<td>2.087</td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. dev.</td>
<td></td>
<td></td>
<td>0.737</td>
<td>0.345</td>
<td>0.260</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COV</td>
<td></td>
<td></td>
<td>0.168</td>
<td>0.157</td>
<td>0.124</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Stats respectively lists mean, standard deviation and coefficient of variation

<sup>b</sup> Relates to a/b = 2 to 8, i.e. models JF5 to JF24 and ZA and ZB
The results of these statistical assessments indicates that the first yield capacity is almost exactly equal to half of the plastic hinge capacity which in itself is only 46% of the test value. The extent of under-estimation is largely due to these first principle methods ignoring the membrane stresses which develop with the growth in out-of-plane deflections. As indicted above, a numerical method is necessary if these are to be quantified and their influence accounted for.

The last two columns of Table 7.4 list the statistics of the plastic hinge comparisons for sub-sets of the test models. The penultimate column is concerned with sub-sets of different panel aspect ratio and plate slenderness while the final column is concerned with panel aspect ratio only.

Examination of these results suggests that panel aspect ratio is influential but only for aspect ratios less than two. The study by Jackson and Frieze concluded that the experimental results did not indicate an influence of aspect ratio. This was confirmed by a limited numerical study but only for panels of aspect ratio of two and above. Accepting that aspect ratio is not of importance for values of two and above, the effect of aspect ratio of unity can be estimated through comparison of the mean value for this aspect ratio, namely, 2.760, with the average of all the models of aspect ratio two and above which is listed at the bottom of the penultimate column, that is, 2.087. This comparison indicates that the effect of using square panels is to increase the strength of similar panels but of larger aspect ratio by approximately 32%.

For panel aspect ratios of two and four, it is possible to identify the further effect of plate slenderness b/t - see the penultimate column of Table 7.4. This suggests that plates of slenderness ratio 60 are some 17% stronger than plates of slenderness ratio 30. This is not the case as an examination of Table 7.2 will quickly demonstrate. This result is merely a reflection of the relatively greater effect of membrane stresses in more slender plates.

If the examination of the effect of aspect ratio is restricted to plates of b/t \( \approx 63 \), the average for the plates of aspect ratio two and greater is 2.291. The enhancement arising from aspect ratio of unity is therefore 2.760/2.291 = 1.205.

Application of the first yield or plastic hinge approaches to design could proceed as follows. Use either approach to determine the relevant plate strip capacity. Multiply this by the corresponding ‘average’ from Table 7.4. This can be done using overall or subset averages depending upon the required accuracy. Should a lower bound estimate be required, multiply by a value equal to the average minus two times the standard deviation.

### 7.6 STIFFENED PLATE EXPERIMENTAL DATA

Clarkson presents the results of tests on three stiffened plates. Local loads were applied atop the stiffeners. Material properties and thicknesses, however, were presented for one grillage only. The plating is relatively thin compared with that used in present offshore helidecks, the width to thickness ratios ranging from 61 to 135 while for helidecks, 30 is far more usual.

Extensive tests and calculations were carried out for behaviour in the elastic range in seeking to identify an appropriate effective width of plating to take as acting with the stiffener. Tests to plastic collapse were then conducted.
7.7 PARAMETERS AFFECTING STIFFENED PLATE BEHAVIOUR

While Clarkson’s paper [8] provides valuable experimental information, more insight into stiffened plate behaviour is gained from the analytical work of Vassilikos [14, 15]. The behaviour is complex when taken into the plastic range as it involves the transition from flexural to in-plane (membrane) action.

For a load applied atop a stiffener, the loaded stiffener initially acts flexurally spanning between the transverses if these are the more stiff or between the end supports if the transverses are less stiff. The extent of plate acting with the stiffener is influenced by two phenomena, shear lag and buckling. Buckling tends to be the more important because it is less dependent on the type of loading - shear lag is far more pronounced under point load than under uniform load conditions - and becomes more pronounced with increasing load levels whereas shear lag effects tend to reduce through stress redistribution under the same conditions. Buckling occurs only in compression regions whereas shear lag is effective under both tensile and compressive loadings - see Figure 7.7. The relevant effective width for plating in hogging, that is, over a transverse for a normally loaded helideck, will be dictated by shear lag. Because of redistribution capabilities at the higher stress levels, however, such shear lag effects are usually ignored.

In the loaded span, as the loaded stiffener deflects, stresses in the plating are generated transverse to stiffener. These membrane stresses in the plating create out-of-plane loading on the adjacent stiffeners forcing them to deflect in sympathy. The unloaded stiffeners act to restrain the loaded member through a mechanism analogous to a beam on an elastic foundation.

The ends of the loaded stiffener are reacted by transverses. If these are adequately stiff, and stiffer than the loaded member, deflections will largely be confined to the loaded span. Alternatively, for a stiffer loaded member, the deflections will extend longitudinally deflecting the transverses. The deflections of the latter generate sinking supports for the stiffeners, which then gain a further component to their overall deflection pattern.

![Figure 7.7](image)
7.8 STIFFENED PLATE CLOSED-FORM SOLUTIONS

For simple structural systems, closed-form solutions to determine the size of stiffeners can be readily derived depending on whether a deflection or stress limit is sought. By restricting deflections, a minimum inertia (second moment of area) is introduced. To limit stresses, a minimum section modulus is required.

DNV set a minimum section modulus requirement - see Appendix D. The stress is limited to 0.73 of yield stress. It appears to assume the stiffener is loaded by a patch load and sustains the entire loading for patch widths less than 0.6 of the plate width. For patches of width equal to the plate width, this reduces to 90% of the patch load. The extent of the patch along the stiffener length is also of influence together with a measure of the support vertical rigidity.

LRS set a stress limit for stiffeners of yield stress under emergency landing conditions.

7.9 FIRST PRINCIPLE PROCEDURES

For stiffened panels with plates of width to thickness ratio approximating 30, structural analysis in the elastic range can proceed accurately on a grillage type approach. This assumes that each stiffener and transverse is independent of its parallel neighbour but that they are rigidly connected at their intersections. Such analyses are now fully computerised.

As discussed in Section 7.4 in relation to plating, either a first yield or fully plastic strength criterion can then be introduced. The former can be readily implemented within a computerised solution, the latter also but requires more sophisticated software than is normally used in a design office. However, the ease with which plastic hinge capabilities can be calculated, particularly with spreadsheets or similar, means that the more complex software is not required. Recall that, when exploiting plastic hinge theory in a grillage type analysis, it is only necessary to consider one span at a time, as demonstrated in Section 7.4.

Should the plate width to thickness ratio exceed 30, allowance is required for the reduction in effective width of plate acting with the stiffener that arises through the tendency of the plate to buckle. A simple accurate and widely used formula for plate buckling effective width $b_e$ is given by the ratio

$$b_e/b = 2/\beta - 1/\beta^2$$  \hspace{1cm} (7.1)

This was derived by Faulkner [48] on the basis of a large number of test results. For plating in tension, a full effective width can be assumed.

For the transverses, an effective width calculation is also required. Recalling that the plate width is now the length of the attached plate, application of the above formula will lead to pessimistic estimates of the effectiveness of attached plating. The reason for this is that equation (7.1) was derived for simply supported plates under conditions in which plate buckling was uninhibited both longitudinally and transversely. Plating welded to transverses is also welded to the intersecting stiffeners. Such plating is therefore relatively heavily framed compared with that associated with the above formulation. Consequently, a larger effective width is entirely appropriate and a value 50% greater than that given by equation (7.1) is recommended. Such effective width should not exceed the spacing of the transverses nor their span/3. The last limitation is based on shear lag requirements and is necessary for typical helideck configurations because it is not possible to mobilise plating at large distances from the web of a beam.
8. STEEL DECKS: BASIS OF CLASSIFICATION SOCIETY FORMULATIONS

8.1 INTRODUCTION

The Classification Societies have not provided any formal bases for their formulations. The general principles behind the LRS approach have been published by Viner [13], but none of the details. In the knowledge that the LRS approach at least is based in part on a permanent set criterion, the comparisons between the test results and the rules predictions presented in Table 7.2 can be examined with a view to establishing any possible relationship. The not infrequent similarities between the predictions of the DNV and GL approaches and those of LRS suggest these two methods may also have permanent set as a criterion.

8.2 COMPARISONS WITH TEST RESULTS

The format used in Table 7.2 is normalised load capacities. Comparisons can be more readily effected using the ratios of the test capacities to the predicted ones: this is done in Table 8.1. The predictions from Hughes’ equation are included for comparison. A statistical assessment of the ratios is given at the bottom of each set.

Table 8.1
Ratios of normalised experimental loads and closed-form predictions

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>JF1</td>
<td>1.58</td>
<td>1.47</td>
<td>1.53</td>
<td>1.14</td>
</tr>
<tr>
<td>JF2</td>
<td>1.58</td>
<td>1.47</td>
<td>1.59</td>
<td>1.14</td>
</tr>
<tr>
<td>JF3</td>
<td>1.13</td>
<td>1.17</td>
<td>1.24</td>
<td>1.07</td>
</tr>
<tr>
<td>JF4</td>
<td>1.05</td>
<td>1.10</td>
<td>1.12</td>
<td>1.00</td>
</tr>
<tr>
<td>JF5</td>
<td>2.25</td>
<td>2.00</td>
<td>1.62</td>
<td>1.04</td>
</tr>
<tr>
<td>JF6</td>
<td>2.25</td>
<td>2.00</td>
<td>1.61</td>
<td>1.04</td>
</tr>
<tr>
<td>JF7</td>
<td>1.36</td>
<td>1.23</td>
<td>1.13</td>
<td>0.69</td>
</tr>
<tr>
<td>JF8</td>
<td>1.72</td>
<td>1.55</td>
<td>1.43</td>
<td>0.88</td>
</tr>
<tr>
<td>JF9</td>
<td>1.48</td>
<td>1.37</td>
<td>1.27</td>
<td>0.81</td>
</tr>
<tr>
<td>JF10</td>
<td>1.79</td>
<td>1.66</td>
<td>1.59</td>
<td>0.98</td>
</tr>
<tr>
<td>JF11</td>
<td>1.11</td>
<td>1.08</td>
<td>1.03</td>
<td>0.80</td>
</tr>
<tr>
<td>JF12</td>
<td>1.31</td>
<td>1.28</td>
<td>1.20</td>
<td>0.95</td>
</tr>
<tr>
<td>JF13</td>
<td>2.21</td>
<td>1.96</td>
<td>1.56</td>
<td>0.97</td>
</tr>
<tr>
<td>JF14</td>
<td>2.16</td>
<td>1.91</td>
<td>1.52</td>
<td>0.95</td>
</tr>
<tr>
<td>JF15</td>
<td>1.75</td>
<td>1.65</td>
<td>1.39</td>
<td>0.85</td>
</tr>
<tr>
<td>JF16</td>
<td>1.40</td>
<td>1.32</td>
<td>1.10</td>
<td>0.68</td>
</tr>
<tr>
<td>JF17</td>
<td>1.89</td>
<td>1.83</td>
<td>1.56</td>
<td>0.98</td>
</tr>
<tr>
<td>JF18</td>
<td>1.83</td>
<td>1.77</td>
<td>1.55</td>
<td>0.95</td>
</tr>
<tr>
<td>JF19</td>
<td>1.12</td>
<td>1.12</td>
<td>0.97</td>
<td>0.77</td>
</tr>
<tr>
<td>JF20</td>
<td>1.42</td>
<td>1.42</td>
<td>1.22</td>
<td>0.97</td>
</tr>
<tr>
<td>JF21</td>
<td>2.09</td>
<td>1.85</td>
<td>1.48</td>
<td>0.92</td>
</tr>
<tr>
<td>JF22</td>
<td>2.13</td>
<td>1.89</td>
<td>1.50</td>
<td>0.94</td>
</tr>
<tr>
<td>JF23</td>
<td>1.95</td>
<td>1.84</td>
<td>1.55</td>
<td>0.94</td>
</tr>
<tr>
<td>JF24</td>
<td>1.89</td>
<td>1.78</td>
<td>1.48</td>
<td>0.91</td>
</tr>
<tr>
<td>ZA</td>
<td>1.30</td>
<td>1.25</td>
<td>1.02</td>
<td>0.74</td>
</tr>
<tr>
<td>ZB</td>
<td>0.80</td>
<td>0.79</td>
<td>0.65</td>
<td>0.56</td>
</tr>
<tr>
<td>Average</td>
<td>1.636</td>
<td>1.529</td>
<td>1.341</td>
<td>0.910</td>
</tr>
<tr>
<td>St. dev.</td>
<td>0.418</td>
<td>0.340</td>
<td>0.254</td>
<td>0.141</td>
</tr>
<tr>
<td>COV</td>
<td>0.255</td>
<td>0.222</td>
<td>0.190</td>
<td>0.155</td>
</tr>
</tbody>
</table>
The table shows that none of the Classification Society formulations appears to demonstrate any consistent relationship with the test results. Except for model ZB, in only one case involving these formulations is the ratio less than unity - JF19 and LRS - indicating that permanent set is expected to occur. Otherwise, based on the COV values, each of these correlations exhibits considerable scatter in its predictions although the LRS approach is the most accurate of such approaches. Hughes’ solution is the most accurate overall although it frequently over-estimates the loads at which permanent set will occur.

Model ZB is of interest as it is the only one that demonstrates a significantly lower capacity than the above predictions. From the information available, at least one possible cause for this difference is identifiable. It relates to the form of section used for stiffening the plate. Whereas all the other models use T-bars or trapezoidal sections that have a reasonable degree of torsion stiffness, Model ZB is stiffened by bulb-flats that have little torsional stiffness. If this is the cause of the relatively larger deflections noted in this model, it is recommended that such section not be used for the stiffening of plating in which non-uniform loading predominates.

It is of interest to compare the above results with those presented in Table 7.4 involving first principle solutions. Both the first yield and plastic hinge approaches realised COVs of about 0.16 compared with the minimum of 0.19 demonstrated above in the case of the LRS predictions and 0.16 in the case of Hughes’ empirical equation. When the models of aspect ratio unity are excluded from the plastic hinge solutions, the COV reduces to 0.12. Repeating this exercise in the case of the Classification Society formulations and the empirical equation makes no practical difference to the above correlations.

This comparison seems to demonstrate that the complications contained within the Classification Society closed-form solutions may not really be justified since more accurate predictions can be obtained using a relatively simple 2-D approach. One possible cause of the inaccuracies of the Classification Society formulations can be found from an examination of the results in Table 8.1. Recalling from Table 7.1 that each group of four JF models relates to one aspect ratio and one slenderness ratio, and within each four, the first pair relates to a smaller b/B than the second pair, it appears than none of the formulations correctly quantifies the effect of the plate width to patch width ratio. The corresponding results for the plastic hinge solution in Table 7.4 clearly demonstrate the more accurate treatment of this effect by this approach.

The relative importance of this ratio was highlighted in Section 7.2 when the parameters affecting the response of patch loaded plates were discussed. It is also an apparently important variable in Hughes’ empirical equation - see Section 5.4. This contains three parameters one of which μ is a measure of this plate width to patch width ratio but not directly since it also contains a variable reflecting the length of the patch. From Table 8.1, it would seem that, for some of the geometries, this empirical equation has correctly captured this effect - see comparisons for JF21 to JF24 - whilst for others – JF1 to JF8 - it is not adequately modelled.
9. ALUMINIUM DECKS: EXPERIMENTS, EXAMPLE CALCULATIONS AND PREDICTIONS

9.1 EXPERIMENTAL DATA

As indicated in the literature review, the only test results available for aluminium decks were those provided through the auspices of Linkleters as licensees of Merlin Teknologi deck systems. The results relate to Merlin’s conventional deck system and include non-structural as well as structural tests. The structural tests covered both skid and wheel loadings and examined plate behaviour, stiffened plate behaviour, and local stiffener web loading at supports. As may be seen in Figure 6.1, one of the plate spans contains a tongue and groove joint while two do not. Tests were conducted on both types of plate spans. The results are limited to overall load and deflections recordings supplemented by brief descriptions of the failures.

Details of the models are given in Table 9.1. They relate to the relevant structural tests from the Merlin Teknologi report. In this table, b, defines the web depth as well as deck panel width, a, the centre-to-centre spacing of the supports or the length of the planks when in the web tests, $t_{\text{min}}$-$t_{\text{max}}$, refers to the variation in deck plate thickness, maximum at the edges, $t_w$, is the web thickness, and A x B gives the load dimensions. For the skids, which were simulated by 75mm diameter tubulars, the extent of transverse contact has been estimated through visual estimation of scaled drawings. The yield stress is quoted as 240 N/mm² which appears to be a guarantied minimum value rather than one obtained by tests. The material is equivalent to 6082 T6.

Each test was normally conducted in two phases, an elastic test with deflections measured including any permanent set followed by a test to failure without deflection readings. Deflections were generally measured immediately under the load, probably towards one end of the tubular during the skid tests.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>b (mm)</th>
<th>a (mm)</th>
<th>$t_{\text{min}}$-$t_{\text{max}}$ or $t_w$, $t_{\text{max}}$ (mm)</th>
<th>A x B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1(1)</td>
<td>100</td>
<td>600</td>
<td>2.5-5.0</td>
<td>600 x φ</td>
</tr>
<tr>
<td>1.2</td>
<td>100</td>
<td>600</td>
<td>2.5-5.0</td>
<td>600 x φ</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>600</td>
<td>2.5-5.0</td>
<td>300 x 300</td>
</tr>
<tr>
<td>Web</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>135.5</td>
<td>800</td>
<td>3.0, 5.0</td>
<td>600 x φ</td>
</tr>
<tr>
<td>4</td>
<td>135.5</td>
<td>600</td>
<td>3.0, 5.0</td>
<td>300 x 300</td>
</tr>
<tr>
<td>Plank</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>100</td>
<td>1500</td>
<td>2.5-5.0</td>
<td>300 x 300</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>2500</td>
<td>2.5-5.0</td>
<td>300 x 300</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>1500</td>
<td>2.5-5.0</td>
<td>600 x φ</td>
</tr>
<tr>
<td>9</td>
<td>100</td>
<td>2500</td>
<td>2.5-5.0</td>
<td>600 x φ</td>
</tr>
</tbody>
</table>

(1) with joint  
(2) tubular 75φ wt 6.3
9.2 PARAMETERS AFFECTING BEHAVIOUR

9.2.1 Basic aspects of behaviour

As discussed above, the stiffener spacings on aluminium decks are such that wheel loads normally span several of these. On the other hand, skids are circular and readily fit within one plate span. Since the test data available concern the open plank section, discussion on the parameters affecting behaviour will be concentrated on this type of section.

For decks under skids the parameters affecting behaviour will be very similar to those influencing steel decks under wheel loads as far as plate response is concerned. Because a skid can be considered as a relatively long patch, the 2-D features of such behaviour will dominate. Complicating features of such behaviour revolve around the fact that the plating between stiffeners is not of uniform thickness and the presence of a groove. Figure 6.1 shows that the plate tapers towards the ends although the central portion is uniform. For the span containing the joint, the extent of uniform plating thickness is approximately half of that used in the continuous spans. For the span containing the joint, opening of the joint is a possible form of failure.

When skid loading is applied atop a stiffener and parallel to it, buckling or crippling of the stiffener web are possible forms of failure. Web buckling involves overall deformation of the web in a column type failure mode. Web crippling on the other hand is a localised form of buckling which occurs immediately adjacent to the loaded flange. Web buckling is probably more likely to occur when a concentrated load is applied directly over or in close proximity to a support. Crippling is more likely where the applied load and the support are remote and will occur at one or other of the locations.

For decks subjected to wheel loads, the loading is spread over several spans. Web buckling is likely to dominate failure.

The preceding discussion has concentrated on local load effects. As in the case of steel decks, global bending response is also to be examined. Similar considerations apply as for the steel decks.

9.3 CLOSED-FORM SOLUTIONS

The LRS rules for helidecks (Appendix F) allow local loads to extend over more than one plate span. They can thus be used to examine both skid as well as wheel loads in this case.

Minimum requirements are given by LRS for the section modulus and the second moment of inertia of stiffeners, which thereby limit the levels of stresses and the deflections.

With web crippling being a likely form of failure for the webs of aluminium decks, procedures are required to estimate such capacities. Zhang [17] identified a number of relevant closed-form formulae (but which however will be more accessible in the paper by Lehmann and Zhang [18]). The source of a number of these was a paper by Roberts [49] which contained only a few test results. A second paper by the same author [50] contained a substantial number of relevant results. These together with those of Zhang were assembled into a database of 145 results.

The results were compared with the predictions of several of the referenced formulae. Some of these only contained geometry variables as they were originally derived from tests on steel girders: web thickness is clearly the dominant variable in this context. Effort concentrated on those formulae containing both yield stress and elastic modulus in order that they could be applied in the present case.

Two formulae were initially found to provide reasonable correlation with the test results.
These were:

\[ P_u = 0.5 t_w^2 \left( \frac{E \sigma_y t_w}{t_f} \right)^{0.5} \left[ 1 + \frac{3c}{d} \left( \frac{t_w}{t_f} \right)^{1.5} \right] \]  \hspace{1cm} (9.1)

\[ P_u = 0.75 t_w^2 \left( \frac{E \sigma_y t_w}{t_f} \right)^{0.5} \]  \hspace{1cm} (9.2)

where

\( P_u \) = failure load
\( t_w \) = web thickness
\( t_f \) = flange thickness
\( c \) = length of load
\( d \) = web depth

and the material properties relate to the web.

In executing the correlation, it was found possible to improve this in relation to equation (9.2) by reducing the exponent on the term in parenthesis to 0.4. Equation (9.1) still produced the better correlation (COV of 0.189 compared with 0.194) and so was selected for use also because it contained the variable reflecting the load length. Although this variable is not particularly influential, many of the tests related to loads of relatively short length compared with those appropriate for helidecks.

Equation (9.1) demonstrated a bias of 1.529 for the ratio of test to predicted failure load. For the present application equation (9.1) was thus used as follows, found by factoring the constant by this bias:

\[ P_u = 0.765 t_w^2 \left( \frac{E \sigma_y t_w}{t_f} \right)^{0.5} \left[ 1 + \frac{3c}{d} \left( \frac{t_w}{t_f} \right)^{1.5} \right] \]  \hspace{1cm} (9.3)

### 9.4 FIRST PRINCIPLE PROCEDURES

The overall distribution of local loads on typical aluminium decks is found using conventional structural analysis techniques. This is particularly important in the case of the open sections from Merlin Teknologi which use spreader beams fixed to the underside of the deck planks, but not to any supporting girders, to spread the local loading between a number of planks. The spreader beams also provide additional torsional restraint to the stiffening elements of the planks.

Plate strip approaches can then be used to design the plating whether for wheel or for skid loads. Because of the relative proportions of the plate and web elements used in these planks, flexural interaction between these elements is likely to be more pronounced than in the case of the steel decks. However, in the first instance such interaction would be ignored unless it can be demonstrated that such an approach is unnecessarily conservative.

Under wheel loads several spans are loaded. The most critical span will depend on whether a first yield approach is being used or one involving plastic hinges. Identification of the critical span is complicated by the tapered nature of the plating which is approximately twice as thick adjacent to the webs as it is at the centre of the span. For the first yield approach and with the end span loaded over most of its length, moments will be largest at the first internal support with the largest span moment occurring in the end span. Despite this, because of the thinner span plating thickness, first yield will occur within the end span. A similar situation arises when examining the onset of hinges in the plastic hinge approach.

For web crippling, a number of first principle methods have been exploited as demonstrated by Roberts. For those examined, it proved possible to develop closed-form expressions to simplify their application. These were considered in Section 9.3 and equation (9.3) was recommended for use.
Web buckling is examined using column buckling procedures. Two complications arise in the application of such procedures. Firstly, the length of web comprising the width of the column section is to be determined. For this, a length of web is found from assuming the load distributes from the edge of the support or concentrated load at 45° to the vertical. The length of web at mid height of the web is the effective width. From geometry considerations, this is simply the length of the support (or concentrated load) plus the web depth. Secondly, the effective length of the column is to be defined. The top and bottom of a web are rigidly connected to the flanges, which would normally result in an effective length of half the web depth. However, the rotational restraint of the flanges cannot be guaranteed to be infinite. For example, in the present case, one of the bottom flanges is effectively an angle section having a table projecting to one side of the web only. Even when the flange is a Tee, only one side of the flanges may be clamped, and the flexural rigidity of the deck plate will not prevent small rotations occurring. All these factors contribute to an effective column length less than the web depth. On the other hand, it would be too pessimistic to assume the web as pinned ended which would result in an effective length equal to the web depth. In the circumstances, an effective length equal to 0.7 times the web depth is an appropriate assumption.

9.5 PREDICTIONS VERSUS TEST RESULTS

Table 9.2 lists the models, and their failure modes and loads. The mode of failure of Model 1.1 was not indicated. The remainder of the models failed by web buckling, web side-sway, or joint separation. Side-sway involves lateral movement on the deck plate relative to the stiffener flanges that are fixed to the supporting girders. This lateral mode of failure is unlikely to occur in practice because many more and longer planks will normally be present, thereby providing sufficient stiffness and strength against this form of failure. Also listed in the table are the predictions for deck plate capabilities conducted in accordance with the DNV and LRS requirements. Although plate deck failure was not observed, it is essential to ascertain that the predictions do not provide capacities in excess of the recorded failure loads. In these calculations, the minimum deck plate thickness was used. This will result in a pessimistic estimate of load capacity.

For application of these formulations, and indeed the closed-form solutions of Hughes [16] and Jackson and Frieze [11] and the first yield and plastic hinge first-principle procedures, modifications are required to cater for the tapered plating. Such changes could evolve around the use of modified thicknesses or spans to realise similar yielding or hinge actions. No attempt is made here, however, to implement such modifications.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Failure mode</th>
<th>Failure load (kN)</th>
<th>DNV (kN)</th>
<th>LRS (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1(1)</td>
<td>Rupture</td>
<td>263</td>
<td>13.8</td>
<td>6.11</td>
</tr>
<tr>
<td>1.2</td>
<td>Web side-sway</td>
<td>235</td>
<td>13.8</td>
<td>6.11</td>
</tr>
<tr>
<td>2</td>
<td>Web buckling @ support</td>
<td>451</td>
<td>-</td>
<td>27.7</td>
</tr>
<tr>
<td>Web</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Web side-sway</td>
<td>177</td>
<td>13.8</td>
<td>6.11</td>
</tr>
<tr>
<td>4</td>
<td>Web side-sway</td>
<td>196</td>
<td>-</td>
<td>27.7</td>
</tr>
<tr>
<td>Plank</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Web buckling @ load</td>
<td>216</td>
<td>-</td>
<td>27.7</td>
</tr>
<tr>
<td>7</td>
<td>Joint opened</td>
<td>147</td>
<td>-</td>
<td>27.7</td>
</tr>
<tr>
<td>8</td>
<td>Web side-sway</td>
<td>145</td>
<td>13.8</td>
<td>6.11</td>
</tr>
<tr>
<td>9</td>
<td>Joint opened</td>
<td>118</td>
<td>13.8</td>
<td>6.11</td>
</tr>
</tbody>
</table>

(1) with joint
Table 9.3
Web failure loads and predictions

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Web load @ skid or patch at failure (kN)</th>
<th>Web reaction @ support at failure (kN)</th>
<th>Web buckling strength @ patch (kN)</th>
<th>Web buckling strength @ support (kN)</th>
<th>Eqn. (9.3) @ skid or patch</th>
<th>Eqn. (9.3) @ support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>131</td>
<td>65.7</td>
<td>127.0</td>
<td>58.0</td>
<td>261</td>
<td>89.7</td>
</tr>
<tr>
<td>1.2</td>
<td>118</td>
<td>58.9</td>
<td>127.0</td>
<td>58.0</td>
<td>261</td>
<td>89.7</td>
</tr>
<tr>
<td>2</td>
<td>165</td>
<td>82.5&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>75.3</td>
<td>37.6</td>
<td>149</td>
<td>79.8</td>
</tr>
<tr>
<td>Web</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>177</td>
<td>177.0</td>
<td>127.0</td>
<td>58.0</td>
<td>261</td>
<td>89.7</td>
</tr>
<tr>
<td>4</td>
<td>65.3</td>
<td>65.3</td>
<td>75.3</td>
<td>58.0</td>
<td>149</td>
<td>89.7</td>
</tr>
<tr>
<td>Plank</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>79.3</td>
<td>39.6&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>75.3</td>
<td>29.0</td>
<td>149</td>
<td>70.0</td>
</tr>
<tr>
<td>7</td>
<td>53.9</td>
<td>27.0&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>75.3</td>
<td>29.0</td>
<td>149</td>
<td>70.0</td>
</tr>
<tr>
<td>8</td>
<td>72.6</td>
<td>36.3&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>127.0</td>
<td>29.0</td>
<td>261</td>
<td>70.0</td>
</tr>
<tr>
<td>9</td>
<td>58.9</td>
<td>29.4&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>127.0</td>
<td>29.0</td>
<td>261</td>
<td>70.0</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> with joint
<sup>(2)</sup> assuming no lateral distribution between webs

Table 9.3 lists the failure loads for the critical web(s) assuming appropriate distributions of the applied loading into the immediately adjacent webs and into the webs at the supports. In calculating the latter, lateral distribution of reactions between webs was not determined so the values listed will represent upper bounds to the reactions. Web buckling and crippling strengths are also listed determined both under the loading and at the supports. The web buckling load was calculated assuming elastic behaviour only using the Euler buckling equation. The corresponding stresses were approximately one quarter of yield confirming the suitability of this assumption.

Where the loads or reactions are less than the strengths, failure in that mode should not occur. Where the loads or reactions are greater than the strengths, failure in those modes is to be expected. If more than one failure mode is likely, that demonstrating the larger ratio of load or reaction to strength is likely to govern. Web buckling is predicted to occur ahead of crippling in all cases. However, side-sway is observed in a number of cases that could be associated with column buckling. In general, failure occurs around the predicted values although frequently in a different mode. Models 2 and 3 are considerably stronger than any of the predictions.
10. BASIS OF PROPOSED GUIDANCE AND COMPLIANCE

10.1 STRUCTURAL CRITERIA FOR PLATES

In identifying structural criteria, account also has to be taken of the nature of the loading. For example, it has been found that the HSE and CAP 437 heavy landing requirement rarely ever governs. This arises because the same structural limitations are being applied in this case as they are for the emergency landing condition which, since the latter represents a load 67% greater (2.5/1.5) than that applicable to the heavy landing case, will always govern. The emergency landing condition was noted as approximating the ‘once in a lifetime’ event. However, more precise statistical definitions of these events are required and can be obtained from measurements of helicopter landing velocities as exploited by Deady [21] and referred to by Garron [22].

As far as the helicopter is concerned, emergency landings can lead to collapse of the undercarriage with the body of the helicopter then impacting onto the deck. This will naturally spread the load leading to a far less onerous condition than when the undercarriage is intact. The undercarriage collapse loads should be available from the manufacturers.

The critical load for the deck is thus the collapse load of the undercarriage. Under emergency landing conditions, provided the deck as a whole remains reasonably intact (and this is largely influenced by the stiffeners which are discussed in the next section), there appears to be no reason why large localised deformations of the plating can not be accepted. Setting practical limits on such deformations can revolve around the extent of available information. As this relates to an emergency condition, and is effectively an ‘accident’ from the helicopter’s standpoint, a load factor of unity is appropriate for consistency with clause 6.2.2 of ISO 2394-1986 (E), General principles on reliability for structures [51]. Even if the manufacturers’ data on undercarriage collapse loads under-estimates these, the reserve of strength available beyond even a sizeable permanent set is considerable so that puncturing of the deck will not occur for even reasonable departures from the quoted collapse values.

The design curves of Jackson and Frieze [11] or Hughes’ [16] empirical equation extend to normalised permanent sets of 0.6 which correspond to 1/40 of the panel width for grade 50 steel and 1/28 for 6082 T6 aluminium. In the case of aluminium, the same proportion of the panel width as for grade 50 steel is obtained by a limitation on the normalised permanent set of 0.4. For a steel deck with stiffeners at 300 mm spacings, a normalised permanent set of 0.6 corresponds to a deflection of 7.5 mm while 0.4 for aluminium leads to 2.5 mm distortion in a 100mm wide deck plate of uniform thickness. These estimates are likely to prove to be on the high side for steel decks since they have been determined for slow material strain rates. In practice, at least a 10 to 15 % enhancement of yield stress can be expected under emergency landing conditions due to the relatively rapid rate of loading. An effective increase in yield stress will reduce the resulting deflections. Aluminium decks are not similarly affected as this material does not exhibit strain rate effects.

For a heavy landing condition, this should be determined from observations of typical landing patterns. Garron refers to 2.4m/s as a typical heavy landing velocity although at the time of the studies by Mainstone [20] and Harding [19], 2 m/s was considered more appropriate. The mode of the Rayleigh distribution fitted by Deady to nearly 1500 observed landings was 0.76 m/s with a mean of 0.93 m/s. These values can be compared with the 1 in 1500 value from Deady of 2.9 m/s and 3.7 m/s referred to by Garron as 1 in 10,000.

As more than one heavy landing can be expected on a helideck during a normal service life of a platform, it seems appropriate to limit any permanent set that might develop in order to reduce the likelihood of providing places for spilled fuel or similar to accumulate. A value of
normalised permanent set of 0.1 for steel decks and of 0.07 for aluminium decks would seem appropriate. These correspond to 1.25 mm of distortion for a steel deck with stiffeners at 300 mm centres, and 0.4 mm for an aluminium deck with stiffeners at 100 mm centres. For steel decks this is less than would normally be permitted as a construction tolerance.

The loads involved in heavy landings should be obtained from simulations or experiments. Manufacturers normally provide undercarriage dynamic loads which could be used but they may need to be reviewed to ensure consistency with the proposed heavy landing velocity. A load factor of 1.5 is recommended, a value widely recommended accounting for variability in oleo characteristics, manufacturers’ data, etc.

Deck plating frequently used in helidecks has a high natural frequency so it will not be affected by the relatively long ‘rise time’ associated with helicopter landings of some 0.05 to 0.1 seconds as recorded by Mainstone and Harding. Thus no plate response factor will normally be required, consistent with Classification Society requirements.

10.2 STRUCTURAL CRITERIA FOR STIFFENED PLATES

Similarly to plating, criteria for stiffened plates must account for the type and category of loading and the consequences of any resulting failures or other exceedances of serviceability such as excessive distortions.

For plating, permanent set is acceptable under emergency conditions since it will not lead to circumstances that will render the helideck unserviceable from the viewpoint of rescue operations, fire-fighting, etc. Permanent set in the stiffened plating would, however, make such operations difficult and should preferably be avoided. Plastic hinge approaches offer more economical designs and should therefore be exploited. By introducing a load factor of 1.5, the benefits of this approach can be realised without the formation of a permanent set. Further safeguards do exist through the enhancement of yield stress due to strain rate effects always recognising that the value of yield stress used is a design value, the real value being some 10 to 12% larger. In the case of aluminium, strain rate effects are negligible and an increase in the load factor to 1.65 is justified.

Since under emergency landing conditions, no permanent set is to be allowed, the load involved is larger than that relevant for the heavy landing condition, the same design approach (plastic hinge) would be used, and similar load factors would be recommended, a separate stiffened plating check under heavy landing conditions is not required.

As for plating, the natural frequency of stiffened steel helidecks is high enough to avoid amplification by helicopter landings. The case for aluminium decks is more marginal. However, bearing in mind the tongue and groove arrangement adopted in such decks, structural damping will be significant and will help to suppress any tendencies to respond dynamically. Thus, again a deck response factor will rarely be required.

The test results for aluminium decks were notable for the number of web failures that occurred. Attention was also drawn by Zhang [17] to the possibility of similar occurrences in steel decks stiffened by trapezoidal sections because of their relatively slender plating compared with that found in rolled stiffener sections. Calculations conducted in the examination of the aluminium deck test results (Section 9.5) confirmed that web buckling could be a governing criterion. The absence of transverse stiffeners at supports in these decks indicates this check will be particularly necessary in these circumstances.
10.3 COMPLIANCE OF LOADING SPECIFICATIONS

The proposed guidance (issued separately) on loading suggests two conditions be considered, the emergency landing and the heavy landing. The first corresponds to the undercarriage collapse loads, and the second to a vertical descent at 2.4 m/s while two-thirds airborne (i.e. two-thirds of weight supported by rotor lift).

Neither of these are considered in the loading specifications presented in CAP 437, HSE guidance, or the Classification Society requirements.

10.4 COMPLIANCE OF CLOSED-FORM SOLUTIONS

For plating, under both emergency and heavy landing conditions, the proposed guidance is given in terms of an allowable permanent set. Only two closed-form solutions for plating assessment account specifically for permanent set, namely, the curves of Jackson and Frieze and the equation of Hughes.

For stiffened plating, a plastic hinge approach is recommended except in the case of cantilevers when a first yield limit is proposed. Plastic hinge approaches are usually considered as first principle procedures although for simple structural systems such as beams they can usually be cast in a closed-form solution format such as demonstrated for plate strips in Section 7.4.2.

Both DNV and LRS set limits on stress in their stiffened plating requirements, based on an elastic approach, that is, plastic hinge action is not permitted.

A closed-form solution was determined for web crippling. It demonstrates somewhat higher variability in comparison with test data than, for example, do the plate strip solutions, with a COV of around 0.19 instead of a maximum of 0.14.

10.5 COMPLIANCE OF FIRST PRINCIPLE PROCEDURES

The plate strip solutions presented in Section 7.4.2 make no allowance for permanent set. They could be extended to take this into account but would still require comparisons with the patch loaded plate experimental results to determine correction factors to compensate for this omission. The additional complexity of including permanent set in plate strip solutions is not justified since the experimental results for plates are available which already take this effect into account, and it is easier to exploit these to provide a correction factor for the plate strip solutions than to modify the plate strip approaches themselves.

For stiffened plating, permanent set is not an issue.

In the case of web column buckling, substantiation is required of the adopted values of effective width and particularly effective length.
11. RECOMMENDATIONS AND IMPROVEMENTS

11.1 LOADING

Present helicopter landing load requirements are specified in terms of maximum take-off weight which seem have little to do with the type of emergency and heavy landing loads likely to be experienced by helidecks during their service life. The guidance proposed attempts to compensate for this by exploiting information on relevant landing gear characteristics, namely, undercarriage collapse loads in the case of emergency landings and maximum wheel loads during vertical descents at 2.4 m/s whilst two-thirds airborne in the case of heavy landings. ABS already permits the use of landing gear characteristics in place of a factored maximum take-off weight under its emergency landing requirement - see Table 4.1. John Brown Engineers & Constructors Ltd [38] also provides similar alternatives in its specifications.

Thus for helicopter landing loads, it is recommended that present requirements relating to a factored take-off weight be replaced by more appropriate ones involving landing gear characteristics. For emergency landing conditions, this is the undercarriage collapse load. For the heavy landing condition, use of loads induced by a helicopter descending vertically at 2.4m/s whilst two-thirds airborne is recommended. Both the descent rate and the extent airborne require further consideration and investigation.

Other requirements relating to loading such as simultaneously acting uniform loads, lateral and dead loadings are recommended to be retained in their present format. Changes, however, are proposed in relation to wind loading. For the emergency landing condition, the simultaneous occurrence of two extremes, namely, the crash landing of a helicopter and a design return period wind, is unlikely. In this case, a 10 year return period wind speed is proposed. For the heavy landing condition, the most appropriate value would appear to be the maximum wind speed in which the helicopter can operate and land. These values are recommended to replace the existing requirements.

For helicopters at rest, only one change is proposed. This relates to wind load for which the installation’s design return period value is recommended.

11.2 DECK RESPONSE

Typical helideck plating has natural periods significantly smaller than the rise times associated with helicopter landings. However, it is recommended that the appropriate calculation be performed to determine the natural period to ensure this expected condition holds. Natural periods of 0.05 seconds and larger require further consideration of dynamic response. In pursuing such investigations, it should be born in mind that the landing gear is in continuous contact with the deck during landing and will provide relatively high damping to any plating dynamic response.

Typical stiffened helideck plating has natural periods somewhat closer to the rise times of helicopter landings more so if the deck is constructed from aluminium. Similar investigations are required as in the case of the plating alone.

Currently, Classification Society requirements ignore deck response whilst those of both CAP 437 and HSE guidance suggest relevant calculations are necessary to determine natural periods but indicate a minimum factor of 1.3 be used almost irrespective of the result of the calculation. The proposed guidance attempts to reflect current needs in which deck response considerations can largely be ignored but should they require further examination then a possibly suitable reference is given.
This reference, Mainstone [20], is one of those originally used in the derivation of the deck response factor that appeared in CAP 437 and subsequently in HSE guidance. It relates to helicopter landings and drop tests onto a concrete landing platform. The flexural rigidity of the platform was such that the available natural frequencies were approximately an order of magnitude less than those of typical steel or aluminium helidecks. This increased stiffness will have led to landing reactions significantly greater than would have been determined from using a stiffened deck as a landing platform. This suggests that the deck response factors in Mainstone are probably not appropriate for typical decks. Such factors could probably best be determined through the use of numerical analysis such as finite elements except that the response of the tyre and undercarriage would require manufacturer input or even prototype testing. For aluminium decks, prototype testing is essential in order to quantify the damping caused by the sealant between the planks.

11.3 LOAD FACTORS

The recommended load factors apply only to the loads as specified in the proposed guidance. Any consideration of load factors requires simultaneous examination of the loads.

11.4 ANALYSIS

A static approach is proposed for the analysis of helidecks consistent with those implicit in present Classification Society, CAP 437 and HSE guidance requirements.

Strictly a dynamic analysis is required to correctly determine forces within a helideck and its supporting structure. This is because a static approach, firstly, ignores energy absorbed dynamically and, secondly in the case of steel, uses a constant value of yield stress whereas a strain rate dependent value is appropriate. For a static analysis, a static value of yield stress should be used. In design, a mill certificate or test house value will be used. This already includes a 10 - 15% enhancement of yield stress compared with the static strength, a value not inappropriate for the analysis of steel helidecks under landings. The yield stress of aluminium is strain rate independent.

However, the effects of dynamics and, in the case of steel of strain rate enhancement of yield stress, have not been quantified for helidecks and similar structures. Thus, until some progress is achieved on either or both of these fronts, the static approach is recommended as it provides an additional although unknown and possibly differential level of safety.

Because of the absence of definitive studies on dynamics and strain rate effects, it is recommended that such assessments are required in order that, firstly, the safety levels implicit in helidecks can be quantified and, secondly, any differential in safety levels between aluminium and steel helidecks can be determined.

11.5 STRUCTURAL ASSESSMENT

11.5.1 Deck Plating

Only two of the Classification Society requirements acknowledge that aluminium might be used in the construction of helidecks. However, the relevant clauses demonstrate an expectation that the deck will be of the same form as a typical steel deck. As this is far from the practice, it is strongly recommended that the requirements be modified to appropriately reflect the use of aluminium for such construction and the varied demands of this compared with those of steel.
The proposed guidance on structural assessment presented allows permanent set in the deck plating to be exploited. In principle, none of the Classification Society requirements permit permanent set to develop. Of the closed-form solutions, occasionally the GL and LRS specifications allow loading to approach this condition.

In seeking to possibly compensate the Classification Society closed-form solutions (DNV, GL and LRS) for their inability to provide for permanent set, account must be taken of their inherent inaccuracy. The comparisons between the first principle procedures, the closed-form solutions and the test results indicated that the first principle procedures were more accurate than the Classification Society closed-form solutions. In particular it was noted that none of the latter correctly accounted for one of the most important of the patch loaded plate parameters, the plate width to patch width ratio. With this difficulty to deal with, it is not possible to offer advice on how best to compensate for the limitations of the Classification Society closed-form solutions regarding a permanent set allowance other than to suggest the use of the first principle procedures or more accurate closed-form solutions.

As discussed above, exploitation of the first principle procedures can be readily accomplished through a simple factoring of the predictions by the average ratio of the test results to the predictions. This average ratio has been determined in the case of the onset of permanent set. Appropriate average ratios could be determined for finite values of permanent set.

The more appropriate approach would be to exploit more accurate closed-form solutions. The empirical design curves of Jackson and Frieze [11] and Hughes’ [16] empirical equation are in this category. However, it was noted that the latter gave predictions skew with respect to the test results and so, by implication, the same can be expected of the curves of Jackson and Frieze. However, an improved equation of a form similar to that of Hughes and also based on the test results could be determined which would be free of this skewness and which would possess an accuracy significantly better than that found for the first principle procedures.

Because an improved empirical equation offers the best accuracy and will be just as simple to implement as Hughes’ formulation, which was noticeably easier to do than in the case of any of the Classification Society closed-form solutions, it is recommended that such an equation be determined together with a measure of its accuracy.

11.5.2 Stiffening Elements

For stiffening elements a plastic hinge approach is proposed. In the absence of load factors, a plastic hinge approach will lead to the onset of permanent set. The proposed load factors, however, will prevent such development.

Two authorities provide closed-form solutions for stiffened plating assessment, and although one exploits the first yield criterion, both are derived on elastic principles and so do not allow for plastic hinge action. Plastic hinge solutions can be expressed in closed-form terms as demonstrated in the case of the plate strip solutions in Section 7.4.2. It is generally not possible to convert elastic based formulations into plastic hinge alternatives. Therefore, the recommendation is that no attempt be made to modify the relevant authority requirements but, instead, their replacement by closed-form plastic hinge approaches similar to those described above should be encouraged.

11.5.3 Web Strength

For aluminium stiffened plating and steel decks with trapezoidal stiffening elements, web failure either due to buckling or crippling is possible. Appropriate checks are required to avoid this. These are discussed above and are strongly recommended to be implemented within the requirements.
11.6 SUPPORTING DOCUMENTATION

In undertaking the literature review, no background documents were made available by the Classification Societies in support of their requirements for helidecks. In pursuing explanations for particular details of the formulations in order to check that the sample calculations had been correctly executed, it became clear that in fact probably none had even been prepared. This is of concern particularly in cases where advanced procedures such as non-linear finite element approaches have been employed in the derivation of the criterion. It becomes of further concern when the final requirements are based on a multi-criteria approach so it is never clear in which criterion range a design falls. Consequently, it is strongly recommended that supporting documentation be made available to describe the basis of the requirements. A Commentary of the type used in API RP 2A [52, 53] is a convenient way of presenting such information. Such an approach is adopted in the draft ISO standard for Topside Structures [6], see Appendix A.

11.7 RISK ASSESSMENT

The above has recommended that both the loading and the criteria by which helidecks used for (fixed) offshore structures are designed should be revised. In the case of loading, the recommendation is to adopt statistical based criteria which take into account the way in which helicopter landing gear responds when subjected to exceptional landings. Two categories are proposed, a notional extreme value corresponding to a helicopter crashing onto the deck and an unusually heavy but otherwise normal landing. The former could arise from mechanical failure over which the pilot has little control and corresponds to collapse of the undercarriage. The latter could arise from pilot mis-judgement leading to a heavy landing for which a descent velocity of 2.4 m/s whilst 2/3rds airborne seems to be appropriate based on limited statistics.

In the case of the design criteria, the recommendation revolves around allowing permanent set to occur in the deck plating but not in the stiffeners/frames supporting such decking.

Without considering specific cases, it is not clear whether the proposed changes in the loading criteria will significantly affect the loads for which the helidecks are to be designed. The changes in the design criteria, however, will definitely introduce significant increases in deck strength and therefore load carrying capacity.
12. REFERENCES

1. HEALTH AND SAFETY EXECUTIVE (DEPARTMENT OF ENERGY)
   Offshore Installations: Guidance on design, construction and certification

2. CIVIL AVIATION AUTHORITY
   CAP 437. Offshore helicopter landing areas: guidance on standards

3. AMERICAN INSTITUTE OF STEEL CONSTRUCTION
   Manual of steel construction. Specification for the design, fabrication and erection of
   structural steel for buildings

4. AMERICAN INSTITUTE OF STEEL CONSTRUCTION
   Manual of steel construction. LRFD Specification for the design, fabrication and
   erection of structural steel for buildings

5. BRITISH STANDARDS INSTITUTION
   design in simple and continuous construction: Hot rolled sections

6. DRAFT ISO STANDARD ISO/WD 13819-1-3 - ISSUED FOR REVIEW AND
   COMMENT. NOT TO BE USED FOR DESIGN
   Petroleum and Natural Gas Industries - Offshore Structures - Part 1-3: Topsides Structure
   2 May 2000.

7. OFFSHORE TECHNOLOGY REPORT – OTN 92 214
   Helideck Structural Requirements

8. CLARKSON, J
   Tests on flat plate grillages under concentrated loads

9. HASLUM, K
   Design of a deck subject to large wheel loads
   European Shipbuilding, No 1, 1970, 2-8.

10. SANDVIK, P C
    Deck plates subject to large wheel loads
    Norwegian Institute of Technology, Division of Ship Structures, Report SK/M28, 1974.

11. JACKSON, R and FRIEZE, P A
    Design of deck structures under wheel loads

12. HUGHES, O
    Design of laterally loaded plating - concentrated loads
13 VINER, A C
*Development of ship strength formulations*

14 VASSILIKOS, E P and DOWLING, P J
*The inelastic large-deflection behaviour of patch-loaded stiffened plates*

15 VASSILIKOS, E P
*The large deflection behaviour of stiffened decks under lateral patch loading*

16 HUGHES, O and CALDWELL, J B
*Marine structures. Selected topics, examples and problems, volume I - plate bending*
The Society of Naval Architects and Marine Engineers, Jersey City, 1991.

17 ZHANG, L S
*Festigkeit von ladungsdecks mit trapezhohlprofilen auf ro-ro-schiffen*

18 LEHMANN, E and ZHANG, L S
*Ultimate load behaviour of trapezoidal stiffened car decks*

19 HARDING, M J H
*A method of measuring helicopter landing loads*
British European Airways, Helicopter Note No 140, October 1963.

20 MAINSTONE, R J
*Structural tests on an experimental helicopter platform*

21 DEADY, M
*Note on landing parameter analysis of the relevance of gaussian and Rayleigh distributions*

22 GARRON, S
*Helicopter induced deck loads*
presented to SNAME’s Eastern Canadian Section, December 1990.

23 AMERICAN PETROLEUM INSTITUTE
*Recommended practice for planning, designing, and constructing heliports for fixed offshore platforms*

24 OFFICE OF AVIATION AND TRANSPORTATION
*Offshore heliport design guide*
Louisiana Department of Transportation and Development, No. OAPT 5100, March 1980.
25 US DEPARTMENT OF TRANSPORTATION. FEDERAL AVIATION ADMINISTRATION
Advisory Circular – Helideck design

26 NATIONAL TECHNICAL INFORMATION SERVICES
Structural design guidelines for helidecks

27 AMERICAN BUREAU OF SHIPPING
Rules For Building and Classing Mobile Offshore Drilling Units, Part 3, Section 5,
Common Structures.

28 BUREAU VERITAS
Classification and construction of Offshore Units, Part 2, Chapter 4, Section 4.3.2.4,
Helicopter decks.

29 DET NORSKE VERITAS
Rules for classification of mobile offshore units - Part 6, Chapter 1 Miscellaneous
notations

30 GERMANISCHER LLOYD
Classification of mobile offshore units, Chapter 3, Section 6 - Helicopter facilities

31 LLOYD’S REGISTER OF SHIPPING
Rules and regulations for the classification of Ships, Part 3, Chapter 9, Section 5,
Helicopter Landing Areas

32 PELL FRISCHMANN ENGINEERING LTD
BPPD West Sole Platform W C. - Unique specification for the design, manufacture and
construction of the new aluminium helideck
prepared for BP Petroleum Development, Pell Frischmann Engineering Ltd, London,

33 HUMPHREYS & GLASGOW LTD
Miller Development - Structural design specification for topsides modules and
miscellaneous structures - Appendix A - design of helideck
prepared for BP Petroleum Development, Document No MLR-B-MO-ST-0200.00, Rev

34 ELF ENTERPRISE CALEDONIA LTD
Piper Redevelopment - Extracts from Piper ‘B’ helideck design procedure

35 ELF ENTERPRISE CALEDONIA LTD
Piper Redevelopment - Extracts from Saltire ‘A’ helideck design procedure

36 MARATHON OIL U.K., LTD
East Brae Topsides structural steel design
Marathon Oil U.K., Ltd, London, Document Control No 7016-M-99-S-S-0010-00,
37 PELL FRISCHMANN ENGINEERING LTD
*Tartan Field Platform - Extracts from helideck specification*

38 JOHN BROWN ENGINEERS & CONSTRUCTORS LTD
*Extracts from typical helideck design procedures*

39 BAYLEY, M J
*Application of aluminium to offshore topside structures*

40 ALCAN OFFSHORE and WIMPEY OFFSHORE
*The design guide on the use of aluminium in offshore structures*

41 ALCAN OFFSHORE
*Suggested aluminium product manufacturers and fabricators list*
Gerrards Cross, September 1991.

42 MERLIN TEKNOLOGI
*Structural design report (for Convdeck)*

43 MERLIN TEKNOLOGI
*Safedeck structural design calculations*

44 MERLIN TEKNOLOGI
*Test report aluminium deck elements Merlin Convdeck*

45 BRITISH STANDARDS INSTITUTION
*BS 7668 Specification for weldable structural steels. Hot finished hollow sections in weather resistant steels*

46 BRITISH STANDARDS INSTITUTION
*CP 118 Structural use of aluminium (Now Superseded)*

47 BRITISH STANDARDS INSTITUTION.
*BS 8118 Structural use of aluminium. Parts 1 and 2*

48 FAULKNER, D
*A review of effective plating for use in the analysis of stiffened plating in bending and compression*
ROBERTS, T M
Patch loading on plate girders

ROBERTS, T M
Slender plate girders subjected to edge loading

INTERNATIONAL ORGANISATION FOR STANDARDISATION
General principles on reliability for structures
ISO, 2394-1986 (E).

AMERICAN PETROLEUM INSTITUTE
Recommended practice for planning, designing, and constructing fixed offshore platforms – Working Stress Design

AMERICAN PETROLEUM INSTITUTE
Recommended practice for planning, designing, and constructing fixed offshore platforms – Load and Resistance Factored Design
8.4.2 Helicopter landing facilities (helidecks or heliports)

8.4.2.1 General

The design and construction of the helicopter landing and take-off area and parking area should be of sufficient size and strength and laid out so as to accommodate the maximum size of helicopter to be used and to adequately resist the greatest impact actions from heavy and emergency landings.

Consideration should also be given in the design to other types of loading, such as personnel, freight, re-fueling equipment and other traffic, snow and ice, rotor downwash, etc.

This code addresses structural considerations only. (See annex A for general guidance on helideck design) Structural design

The supporting structure, deck plate and stringers should be designed to resist the effects of local wheel or skid actions, acting in combination with other actions, in the most severe location for the element of structure being considered. Helicopters should be considered to land anywhere within the designated landing area and parked or stowed anywhere on the helideck.

The helideck and its supporting structure may be fabricated from steel, aluminium alloy or other appropriate material. The following requirements are specified for a steel structure, but may be simply modified for use with an aluminium structure designed to an appropriate international or other code.

Where the supporting structure consists of tubular trusses, these should be checked for vortex shedding excitation.

All helideck loadings should be analysed using a static elastic structural method to determine the distribution of forces and moments. The helicopter shall be so positioned to maximise the loadings on the element being considered. Where deck plate is required to contribute to primary structural strength it shall be modelled using finite elements that are appropriate to its performance and checked using a relevant code of practice.

The structural design shall be checked for the serviceability and ultimate load conditions appropriate to the member being considered as follows:

- deck plate and stiffeners - ultimate strength under all load conditions
- support structure - ultimate strength under all load conditions
- permanent deflection limited after an emergency landing

Deck plate may be designed to allow a permanent set not exceeding 0.025 of the plate width under helicopter emergency landing loads. Stiffening elements and the supporting structure may be designed using plastic hinge theory. Cantilever elements should be designed using a first yield solution.

The webs of stiffeners should be assessed locally under landing gear loads due to helicopter emergency landings and at supports. Closed form solutions may be used to check for web crippling.

Web buckling should be checked from first principles.

8.4.2.2 Action combinations and action factors

Two action conditions should be considered:

- Emergency landing
- Helicopters at rest
Both conditions include serviceability requirements.

Helicopter actions should be treated as imposed actions and applied together with other imposed actions, dead loads and environmental actions.

8.4.2.3 Emergency landing condition

Imposed actions:
- Helicopter landing gear design collapse loads
- Structural response factor for the design of the supporting structure
- Area load of 0.5 kN/m²
- Horizontal force of 50% of the landing gear collapse load

Dead loads:
- Self weight of helideck structure and fixed appurtenances

Environmental actions:
- Maximum operating wind load on the structure

Under emergency landing conditions, local deformation of plate and stiffeners may be tolerated provided that the overall integrity and function of the helideck are not compromised. If elastic design methods are used, a factor of unity may be adopted.

Normal action factors should be used in design as stated in Section 7

Guidance on the loadings to be considered is given below.

8.4.2.3.1 Helicopter landing gear collapse loads

The maximum dynamic local actions from an emergency landing may be determined from the collapse load of the landing gear. This should be obtained from the helicopter manufacturer.

Alternatively, default values may be used for design by considering an appropriate distribution of the total impact load of 2.5 MTOW (maximum take off weight).

A single main rotor helicopter may be assumed to land simultaneously on its two main undercarriages or skids. A tandem main rotor helicopter may be assume to land on the wheels of all main undercarriages simultaneously. Local (patch) loads should be used in design corresponding to the configuration of the landing gear.

For single main rotor helicopters the total loads imposed on the structure should be taken as concentrated loads on the undercarriage centres of the specified helicopter divided equally between the two main undercarriages. For tandem main rotor helicopters the total loads imposed on the structure should be taken as concentrated loads on the undercarriage centres of the specified helicopter and distributed between the main under-carriages in the proportion in which they carry the maximum static loads. The concentrated undercarriage loads should normally be treated as point loads but where advantageous a tyre contact area may be assumed in accordance with the manufacturer's specification. The maximum take-off weight and undercarriage centres for which the platform has been designed and the maximum size and weight of helicopter for which the deck is suitable should be recorded.

Information on the dimensions and maximum take-off weights of specified helicopters is given in Annex A.

8.4.2.3.2 Structural response factor

The dynamic load determined as above should be increased by a structural response factor to account for the sympathetic response of the helideck structure. The factor to be applied will
depend on the natural frequency of the deck structure. Unless values based upon particular undercarriage behaviour and deck frequency are available, a minimum structural response factor of 1.3 should be used.

8.4.2.3.3 Area imposed action

To allow for snow and ice actions, minor equipment accidentally left on the deck, etc an a general area load of 0.5 kN/m² should be included.

8.4.2.3.4 Horizontal loading

The helideck should be designed to resist concentrated horizontal imposed loads equivalent to half the maximum take-off weight of the helicopter, applied at the main landing gear locations and distributed in proportion to their vertical loading. This should be applied at deck level in a direction to produce the most severe loading conditions for the element considered. Dead load of structural members The dead load supported by the member concerned should be calculated.

8.4.2.3.5 Wind loading

Wind loading on the helideck structure should be applied in the direction which, together with the horizontal imposed loading, will produce the most severe loading condition for the element considered.

8.4.2.4 Helicopter at rest condition

**Imposed loads:**

- Helicopter static loads (local landing gear local patch loads)
- Area load Helicopter tie-down loads, including wind loads from a secured helicopter

**Dead loads**

- Helideck structure and fixed appurtenances self weight

**Environmental actions:**

- Wind loading
- Installation motion

Guidance on the loadings to be considered is given below.

8.4.2.4.1 Helicopter static loads

All parts of the helideck accessible to helicopter should be designed to carry an imposed load equal to the maximum take-off weight of the helicopter. This should be distributed at the landing gear locations in relation to the position of the centre of gravity of the helicopter.

8.4.2.4.2 Area load of 2.0 kN/m²

To allow for personnel, freight, refuelling equipment and other traffic, snow and ice, rotor downwash, etc, a general area load of 2.0 kN/m² should be included.

8.4.2.4.3 Helicopter tie-down loads

Each tie-down should be designed to resist the total wind load imposed by a storm wind with a 100-year return period on the design helicopters.

8.4.2.4.4 Dead load of structural members

The dead load supported by the member concerned should be calculated.
8.4.2.4.5 Wind loading

Wind loading on the helideck structure should be applied in the direction which, together with the horizontal imposed loading, will produce the most severe loading condition for the element considered.

Consideration should also be given to the additional wind loading from a secured helicopter as noted above.

8.4.2.4.6 Installation motion

The effect of acceleration forces and other dynamic amplification forces arising from the predicted motions of the installation in the storm condition with a 100-year return period should be considered.

8.4.2.5 Resistance factors

Normal resistance factors should be applied.

8.4.2.6 Safety net arms and framing

Safety nets for personnel protection should be installed around the landing area except where structural protection exists. The netting used should be of a flexible nature, with the inboard edge fastened level with, or just below, the edge of the helicopter landing deck. The net itself should extend at least 1.5 metres in the horizontal plane and be arranged so that the outboard edge is slightly above the level of the landing area but by not more than 0.25 metres so that it has an upward and outward slope of at least 10°. The supporting structure associated with the safety net should be capable of withstanding without damage a 75 kg weight being dropped into an area of 0.25 m² from a height of 1 metre.

8.4.2.7 Helicopter tie-down points

Sufficient flush-fitting tie-down points should be provided for securing the helicopter types for which the landing area is designed. They should be so located and be of such construction as to secure the helicopter when subjected to weather conditions of a severity unlikely to be exceeded in any one year.

They should also take into account any recommendations made by the aircraft manufacturer and where significant, the inertial forces resulting from the movement of floating platforms.

...............................................................

APPENDIX A - COMMENTARY

:  

A.8.4.2 Helicopter Landing Facilities (helidecks or heliports)

A.8.4.2.1 General

The helideck should be designed to satisfy the requirements of ICAO (International Civil Aviation Authority) Annex 14 Volume II – Heliports and the relevant national or regional civil aviation authority.

The helicopter landing facilities should be large enough, and have sufficient clear approach and departure paths to enable any helicopter intended to use the landing area to land and take off safely in any wind and weather conditions permitting helicopter operations.
The design should take account of not only the capacity of the helicopter landing area required to accommodate the largest type of helicopter intended for normal use, but also situations where it is reasonably foreseeable that a larger and heavier helicopter might need to use it, e.g. during an emergency.

The landing area should be situated so that it is located on the Installation with respect to prevailing wind conditions, in such a position that any structure induced airflow and temperature effects are minimised;

Turbulent airflow across the landing area can be caused by wind flow around adjacent structures, including flare stacks and turbine exhausts, which can also cause temperature gradients. These effects can seriously influence helicopter handling or performance characteristics.

Landing areas situated directly on top of deep slab-sided structures such as accommodation modules, have been known to suffer from excessive vertical airflow components unless there is sufficient separation to allow airflow beneath the helideck.

For this reason the combined effects of airflow direction and turbulence, prevailing wind and Installation turbine exhaust emission, should be determined for each Installation. Suitable wind tunnel model tests should be carried out to confirm the suitability of the arrangements. The resulting information should be made available to the helicopter operator and the relevant national Aviation Authority. As a general rule, the vertical component of airflow resulting from wind velocities of up to 25 metres per second should not exceed ± 0.9 metres per second over the landing area at main rotor height.

Detailed guidance on the location of helidecks, necessary markings, lighting and protection of obstacle-free environment, effect of air turbulence and temperature gradient, is available in national and international codes.

**Structural design**

Installations may be designed to accommodate a particular type of helicopter. Greater operational flexibility may result from a classification system of design.

The helicopter landing and parking areas should be designated for the helicopter with the most critical loading characteristics anticipated to use the facility. Design should consider not only helicopters intended for normal use, but also situations where it is reasonably foreseeable that other helicopters might need to use it, e.g. during an emergency.

Any permanent deformation of the supporting structure should be assessed for the emergency landing condition to confirm that its extent will not be such as to hamper rescue and fire fighting or to prevent other helicopters landing once the area has been cleared.

The deck plate and stiffeners may be designed by a method utilising the ultimate strength of the section, e.g. plastic hinge theory.

When considering a stiffened plate with an open stiffener cross-section, each stiffener and its associated plating may be treated as an independent girder. For the sagging regions of such girders, the thickness of the plating should be determined using a buckling effective width formula such as $2/\beta - 1/\beta^2$, where $\beta$ is a non-dimensional plate slenderness parameter given by $(b/t)(F\sqrt{E})^{0.5}$, $b$ is the stiffener spacing, $t$ the plate thickness, $F\sqrt{E}$ the plate yield stress and $E$ the elastic modulus. A similar method may be used for a closed stiffener cross section (e.g. for aluminium alloy planks). The full torsional stiffness of the section may be exploited to distribute the load across the deck.
A.8.4.2.2 Action Combinations and Action Factors

The type of helicopter most critical to the design will usually be the largest and heaviest helicopter to use the facility. Governing load conditions will usually arise from the maximum wheel loads from the emergency landing condition, depending on the structural elements being considered.

A.8.4.2.3 Emergency landing condition

The emergency landing condition is an accidental action condition expected to occur very infrequently and resulting from such serious events as loss of power, major pilot mishandling or fouling of landing gear during take-off and landing. Where the helicopter landing gear collapses, the body of the helicopter may then impact onto the deck, distributing the impact load further.

A helicopter heavy landing may occur infrequently as a result of an unfavourable combination of factors such as bad weather, minor mechanical problems and slight pilot mishandling. The consequent actions on the helideck structure will be within the envelope for the emergency landing condition.

Therefore, this load condition is not considered further.

For the emergency landing condition, a reduced general area load of 0.5 kN/m² to account for the presence of snow and ice, incidental debris, etc, may be used.

A.8.4.2.3.1 Helicopter landing gear collapse loads

The maximum size of helicopter should be determined for each helicopter landing area in terms of the D value defined below. The D value should be qualified by one of the following statements as necessary ‘For single main rotor helicopters’ or ‘For tandem main rotor helicopters’.

Design criteria based on helicopter size and weight are summarised in Table A8.4.2.4.1 below.

### TABLE A8.4.2.4.1
Helicopter weights and dimensions

<table>
<thead>
<tr>
<th>Type</th>
<th>D value (m)</th>
<th>Rotor height (m)</th>
<th>Rotor diam. (m)</th>
<th>Max. weight (kg)</th>
<th>Landing net size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolkow Bo 105D</td>
<td>11.81</td>
<td>3.80</td>
<td>9.90</td>
<td>2300</td>
<td>Not reqd.</td>
</tr>
<tr>
<td>Bolkow 117</td>
<td>13.00</td>
<td>3.84</td>
<td>11.00</td>
<td>2300</td>
<td>Not reqd.</td>
</tr>
<tr>
<td>Augusta A109</td>
<td>13.05</td>
<td>3.30</td>
<td>11.00</td>
<td>2600</td>
<td>Small</td>
</tr>
<tr>
<td>Dauphin SA365N2</td>
<td>13.68</td>
<td>4.01</td>
<td>11.93</td>
<td>4250</td>
<td>Small</td>
</tr>
<tr>
<td>Sikorsky S76B&amp;C</td>
<td>16.00</td>
<td>4.41</td>
<td>13.40</td>
<td>5307</td>
<td>Medium</td>
</tr>
<tr>
<td>Bell 212</td>
<td>17.46</td>
<td>4.80</td>
<td>14.63</td>
<td>5080</td>
<td>Not reqd.</td>
</tr>
<tr>
<td>Super Puma AS 332L2</td>
<td>19.50</td>
<td>4.92</td>
<td>16.20</td>
<td>9250</td>
<td>Medium</td>
</tr>
<tr>
<td>Super Puma AS 332L</td>
<td>18.70</td>
<td>4.92</td>
<td>15.00</td>
<td>8599</td>
<td>Medium</td>
</tr>
<tr>
<td>Bell 214ST</td>
<td>18.95</td>
<td>4.68</td>
<td>15.85</td>
<td>7936</td>
<td>Medium</td>
</tr>
<tr>
<td>Sikorsky S61N</td>
<td>22.20</td>
<td>5.64</td>
<td>18.90</td>
<td>9298</td>
<td>Large</td>
</tr>
<tr>
<td>EH101</td>
<td>22.80</td>
<td>6.65</td>
<td>18.60</td>
<td>14290</td>
<td>Large</td>
</tr>
<tr>
<td>Boeing BV234LR Chinook**</td>
<td>30.18</td>
<td>5.69</td>
<td>18.29</td>
<td>21315</td>
<td>Large</td>
</tr>
</tbody>
</table>

* With skid fitted helicopters, the maximum height may be increased with ground handling wheels fitted.

** The BV234 is a tandem rotor helicopter and in accordance with ICAO Annex 14 Volume II the helideck size is 0.9 of the helicopter D value, i.e. 27.16m.
A.8.4.2.3.2 Structural response factor

The natural period of the landing area should be evaluated. Where the natural period of the deck exceeds 0.05 seconds (natural frequency 20 Hz), significant dynamic enhancement of the loading on the deck during landing will occur.

4.4.2.6 A method utilising the ultimate capacity of the section may be employed.

4.4.2.7 Safety net arms and framing

enough to withstand, without damage, a 75 kg weight being dropped from a height of 1 metre.

A safety net designed to meet these criteria should not act as a trampoline giving a 'bounce' effect. Where lateral or longitudinal centre bars are provided to strengthen the net structure they should be arranged to avoid causing serious injury to persons falling on to them. The ideal design should produce a hammock effect which should securely contain a body falling or jumping into it, without injury.
APPENDIX B

HELIDECK REQUIREMENTS

AMERICAN BUREAU OF SHIPPING
PART 3  SECTION 5
Common Structures

3/5.1 General

3/5.1.1 Materials
These Rules, except where specified otherwise, are intended for drilling units constructed of steel, manufactured and having the properties as specified in Section 2/2. Where it is intended to use steel or other material having properties differing from those specified in Section 2/2, the use of such material and the corresponding scantlings will be specially considered.

3/5.1.2 Scantlings
Scantlings of the major structural elements of the unit are to be determined in accordance with these Rules. Scantlings of structural elements which are subjected to local loads only, and which are not considered to be effective components of the primary structural frame of the unit, are to comply with the applicable requirements of "Rules for Building and Classing Steel Vessels" or "Rules for Building and Classing Steel Barges".

3/5.1.3 Surface-Type Drilling Units
Surface-type drilling units are to have scantlings that meet the requirements of "Rules for Building and Classing Steel Vessels" or "Rules for Building and Classing Steel Barges", as applicable. Special consideration is to be given to the items noted in Section 3/6.

3/5.1.4 Scantlings and Corrosion Control (1991)
Where deemed necessary to suit particular type and service of the unit or the space, a reduction in scantlings in association with protective coatings may be considered. In such instances, the justification for the reduction is to be submitted for review together with the particulars of the coating including the program for maintenance. The plans are to show the required scantlings and the proposed scantlings, both suitably identified. Where any of the proposed reductions are approved, a notation will be made in the Record that such reductions have been taken. No reduction in scantlings will be permitted where the scantlings are determined by applying the requirements of 3/2.1 in conjunction with the allowable stresses given in 3/4.5. In cases where scantlings are based on 3/2.1 and 3/4.5, and corrosion control methods are not provided, the scantlings are to be suitably increased.

3/5.3 Helicopter Deck

3/5.3.1 General
Plans showing the arrangement, scantlings, and details of the helicopter deck are to be submitted. The arrangement plan is to show the overall size of the helicopter deck and the designated landing area. If the arrangement provides for the securing of a helicopter or helicopters to the deck, the predetermined position(s) selected for the secured helicopter(s), in addition to the locations of deck fittings for securing the helicopter, are to be shown. The type helicopter to be considered is to be specified and calculations for appropriate loading conditions are to be submitted.

3/5.3.2 Structure
Scantlings of helicopter decks and supporting structure are to be determined on the basis of the following loading conditions, whichever is greater, in association with the allowable factors of safety shown in Table 3/5.1:

a. Overall Distributed Loading A minimum distributed loading of 20 kN/m² (400 lb/ft²) is to be taken over the entire helicopter deck.

b. Helicopter Landing Impact Loading A load of not less than 75% of the helicopter maximum take-off weight is to be taken on each of two square areas, 0.3 m × 0.3 m (1 ft × 1 ft). Alternatively, the manufacturer's recommended wheel impact loading will be considered. The deck is to be considered for helicopter landings at any location within the designated landing area. The structural weight of the helicopter deck is to be added to the helicopter impact loading when considering girders, stanchions, truss support, etc. Where the upper deck of a superstructure or deckhouse is used as a helicopter deck and the spaces below are normally manned (quarters, bridge, control room, etc.) the impact loading is to be multiplied by a factor of 1.15.

c. Stowed Helicopter Loading If provisions are made to accommodate helicopters secured to the deck in a predetermined position, the structure is to be considered for a local loading equal to the manufacturer's recommended wheel loadings at maximum take-off weight, multiplied by a dynamic amplification factor based on the predicted motions of the unit for this condition, as may be applicable for the unit under consideration.

In addition to the helicopter load, a uniformly distributed loading of 490 N/m² (50 kgf/m², 10.5 lb/ft²), representing wet snow or ice, is to be considered, if applicable. For the girders, stanchions, truss supports, etc., the structural weight of the helicopter deck is also to be considered.

d. Loading due to Motions of Unit The structure supporting helicopter decks is to withstand the loads resulting from the motions of the unit. For self-elevating drilling units, the loads are to be in accordance with 3/6.5.1c and 3/6.5.1d.
APPENDIX C

HELIDECK REQUIREMENTS

BUREAU VERITAS
4-3.1.6. Testing loads

Testing loads are loads sustained by the structure during testing phases of tanks or equipment.

4-3.1.7. Temporary construction loads

In accordance with the provisions of Chapter 1, temporary construction loads not resulting from the tests required to be performed by the applicable Rules requirements are not subject to review by the Society unless a specific request is made. The attention of the Builder is however called upon the provisions of Chapter 5 concerning construction procedures liable to affect, for instance by prestressing, the strength of the unit.

4-3.2. Fixed and operational loads

4-3.2.1. General

The fixed and operational loads defined in 4-3.1.2. and 4-3.1.3. are to be clearly specified using a format acceptable by the Society. Where stated, minimum Rules prescribed loads are to be taken into consideration.

4-3.2.2. Load distribution

For the purpose of overall structural calculations, a complete description of load distribution is to be provided.

A sufficient number of load cases are to be defined, adequately representing all possible distributions in each condition of operation, unless corresponding restrictions are entered in the Operating Manual.

4-3.2.3. Loads on decks

4-3.2.3.1.

Operational loads acting on decks are to be clearly specified on the permissible loadings decks drawings required in Chapter 1. The drawings are to evidence all distributed and concentrated loads in all deck areas.

For the purpose of local scantling, design distributed deck loads, including deck self-weight, are not to be taken less than given on Table 4-3.2.3.1.

\[
\begin{array}{|c|c|}
\hline
\text{Deck area} & \text{Minimum design loads (kPa)} \\
\hline
\text{Non loaded decks} & 2.0 \\
\text{Crew and similar spaces} & 4.5 \\
\text{Work areas} & 9.0 \\
\text{Storage areas (1)} & \text{minimum 13.0 or } \rho H \\
\hline
\end{array}
\]

Where:

\( H \) is the storage height in meters

\( \rho \) is the cargo specific weight, in kN/m³

If the value of this specific weight is not specified, \( \rho = 7 \) is to be taken for calculation.

Note:

- for decks used as helidecks, refer also to 4-3.2.4.
- for exposed decks, refer also to 4-3.2.8.

4-3.2.3.2.

As appropriate according to deck use, operational concentrated loads applied on decks are to be combined with the distributed loads given in Table 4-3.2.3.1.

4-3.2.4. Loads on helidecks

4-3.2.4.1.

The design of the helideck is to be based on the loads associated with the largest helicopter intended to be used.
4.3.2.4.2.

The following information concerning the largest helicopter intended to be used are to be supplied and will be included in the Design Criteria Statement:

- type and maximum take-off weight \( Q \);
- distance between main wheels or skids;
- length of skid contact area or distance between main wheels and tail wheel;
- print area of wheels;
- rotor diameter and overall length measured across main and tail rotors or across main rotors for helicopters with tandem main rotors.

In addition, general arrangement of the helicopter deck is to be provided.

4.3.2.4.3.

Two design loading cases, at least, are to be considered:

- helicopter stowed;
- helicopter hard landing;

Other conditions may be considered as design cases, provided they lead to an equivalent degree of safety.

4.3.2.4.4.

Corresponding loads are to be calculated according to the Recommended Practice "Evaluation of loads on offshore units and installations" or according to applicable national standards.

4.3.2.5. Loads due to operations

4.3.2.5.1.

For operational equipment liable to induce, when in use, important loads within the structure of the unit, the party applying for classification is to provide, in accordance with Chapter 1, all necessary information on these loads, such as:

- for a drilling rig, loads induced by rig components (derrick, turntable, tensioners, etc.) in the various situations of drilling activities;
- for a revolving crane, calculations of loads on crane pedestal during crane operation, and those on pedestal, boom and hook rests, for the stowed situation;
- stinger and tensioner loads (pipelaying);
- for the different lifting and handling equipment, the precise indicative loads they may induce in the static unit (magnitude, direction, etc.), with their nature (permanent, normal, extreme, etc.)

4.3.2.5.2.

Loads are to adequately include a static and dynamic components. Induced motions considered in load are to be specified.

4.3.2.5.3.

Unless otherwise documented the dynamic actions and test loads induced by lifting and handling equipment are to be taken as provided for in the "Rules for the Classification and Certification of Lifting Appliances of Ships and Offshore Structures".

4.3.2.6. Hydrostatic loads

4.3.2.6.1.

For calculation of hydrostatic loads on outer shell are to be considered the maximum and minimum draughts in each condition of operation. If the shell forms tank boundary, the maximum inner pressure is to be considered as well. Refer also to 4.3.3.8.

4.3.2.6.2.

The panels forming boundaries of ballast, fuel oil and other liquid compartments are to be designed for a liquid specific gravity at least equal to that of sea water.

Unless adequate means are provided to the satisfaction of the Society account is not to be taken of counter-pressures from adjoining tanks and compartments. Minimum external counter-pressure may be considered where significant.
APPENDIX D

HELIDECK REQUIREMENTS

DET NORSKE VERITAS
SECTION 2
HELCOPTER DECKS

Contents
A. General
A 100 Classification
A 200 Scope
A 300 Documentation
A 400 Materials
A 500 Steel-aluminium connections
B. Design Loads
B 100 General
B 200 Landing impact forces
B 300 Gravity and inertia forces (due to unit's motions and accelerations)
B 400 Environmental loadings
B 500 Load on the safety net
C. Strength Requirements
C 100 General
C 200 Plating and stiffeners
C 300 Girders and supporting structures
C 400 Welded aluminium decks
C 500 Safety net
C 600 Tie-down points

A. General

A 100 Classification

101 The requirements in this section apply to mobile offshore units with erected landing platforms for helicopters or landing areas arranged directly on decks or top of deckhouses.

102 Units complying with the requirements given in this section may be given the class notation HELDK.

Guidance note:
It will be necessary also to comply with national regulations of the country in which the unit is registered and/or where the unit is operating. This applies to e.g.:
— size, arrangement and location of helicopter deck and marking of this
— free areas (sectors) for approach and take-off
— rescue and fire fighting equipment
— fire protection
— location of deck (e.g. if the helideck is to be located on a living quarter module, a separation between the deck and the adjacent structure of minimum 1 m shall be provided (NMD)).

If requested by national authorities, the Society will undertake supervision related to items as mentioned above.

A 200 Scope

201 The following matter is covered by classification:
— Structural strength of helicopter deck with supporting structure, safety net and tie-down points.

A 300 Documentation

301 Plans showing structural design and details, material scantlings and particulars of materials to be applied, are to be submitted for approval. Strength calculations are also to be submitted, including information on all design loads. Type and maximum take-off mass of helicopter are to be specified.

302 An arrangement drawing is to be submitted for information.

A 400 Materials

401 The grades of steel and aluminium materials are to be in compliance with the requirements to structural materials given in Pt.3 Ch.1.

A 500 Steel-aluminium connections

501 In sea exposed areas, to prevent galvanic corrosion, a non-hygroscopic insulation material is to be applied between steel and aluminium. Bolts with nuts and washers are normally to be of stainless steel. The bolts are to be fitted with sleeves of insulating material.

502 In high shear exposed bolt connections, when located in reasonably dry areas (not exposed to sea spray), a friction connection is preferred. The bolts, nuts and washers are normally to be of stainless steel. Details of the connection are to be submitted for approval.

503 Horizontal inertia forces in bolted connections may be required to be taken up by metal to metal stoppers with insulation tape in the gap.

504 Aluminium superstructures which are provided with insulating material between aluminium and steel are to be earthed to the hull.

505 Any bimetallic connection flats are to be delivered from an approved manufacturer and with DNV certificate.

B. Design Loads

B 100 General

101 The scantlings are to be based on the most unfavourable of the following conditions:
— landing condition
— towed condition (helicopter landed onboard at sea).

Guidance note:
The landing condition will be governing for strength of plates and stiffeners and normally also for girders and supporting structure.

The following loads are in general to be considered:
— landing impact forces
— gravity and inertia forces of the helicopter in stowed position.

102 For landing platform (erected as a separate structure) the following loads are also to be considered:
— gravity and inertia forces of the structure
— wind forces
— snow and ice loads.

103 For landing areas on integrated decks, load combinations with design loads required by the main class are to be considered when relevant.

B 200 Landing impact forces

201 The total vertical force from the helicopter during landing is to be taken not less than:
\[ P = 2g_0 M_0 \text{ (kN)} \]

\[ M_0 = \text{maximum take-off mass in t of helicopter.} \]

The total force \( P \) is to be considered as distributed on the helicopter's landing gear in the same manner as when the helicopter is resting on a horizontal surface and the helicopter's centre of gravity is in its normal position in relation to the landing gear.

202 The design pressure under wheel loading is normally given by:

\[ p = \frac{f P}{A} \text{ (kN/m}^2) \]

\[ P = \text{total vertical landing impact force as given in 201} \]

\[ f = \text{fraction of } P \text{ applicable to the load area in question} \]

\[ A = \text{design load area in m}^2 \text{ under landing impact condition.} \]

The load area as indicated in Fig. 1 are defined as:

- the footprint area of individual wheels or
- the rectangular enveloped area of footprints of a wheel group.

In general the scantlings are to be checked according to both definitions. If, however, the distance \( e \) between individual footprints is less than the breadth \( b_1 \) of the prints, the load area may normally be calculated for the group of wheels only.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wheels in group</td>
<td>Footprint dimensions (real contact areas between tyres and deck)</td>
<td>Design load area for axle parallel to stiffeners</td>
</tr>
<tr>
<td>Single wheel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double wheel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1
Definition of load area

203 A horizontal component of the landing impact force is to be combined with the vertical force when calculating the strength of the supporting structure.

The horizontal component is normally not to be taken less than 0.2 \( P \).

B 300 Gravity and inertia forces (due to unit's motions and accelerations)

301 The static and dynamic design forces caused by the helicopter in stowed position and by the platform structure itself are to be taken in accordance with the design loads for heavy units given in Pt.3 Ch.1.

302 For landing conditions the heel and trim need normally not be considered.

B 400 Environmental loadings

401 The wind pressure is to be calculated using 'gust' (3 sec, averaging time interval) wind velocities (see Pt.3 Ch.1 Sec.4).

Guidance note:

When evaluating wind pressures the following listed one minute sustained wind velocities may normally be used as a basis for calculating the gust wind velocities:
V_{\text{lim}, 10} = 30 \text{ m/s for the landing conditions}
V_{\text{lim}, 10} = 55 \text{ m/s for the stowed conditions}

---end-of-Guidance-note---

402 For structures where wind suction forces may be of importance, e.g. bolted structures, wind lift forces are to be taken into account. The total lift force (P_W) may then be calculated as:

$$P_W = 1.2 A_D \text{ (kN)}$$

where

$$A_D = \text{deck area in m}^2.$$

---end-of-Guidance-note---

403 Ice loading is to be taken into account in the stowed condition load case.

---Guidance note---

Ice loading may normally be considered by assuming a 50 mm covering to all external surfaces.

---end-of-Guidance-note---

B 500 Load on the safety net

501 The test load for the safety net and safety net supporting structure surrounding a helicopter deck, is not to be taken less than 75 kg dropped from 1 m.

---Guidance note---

Approximate calculations may be based on a static load of 0.2 ton per meter run of net. For soft, hammock type nets this load may be converted into 0.02 m kN/m acting along outer and inner rails in an inward plane 30° below the net plane, see Fig. 2.

---end-of-Guidance-note---

---Fig. 2---

Static load on safety net

---end-of-Guidance-note---

C. Strength Requirements

C 100 General

101 Decks for helicopters supported on wheels with pneumatic tyres are to have plating and stiffeners in accordance with the requirements given in 200 to 300.

102 The plating and stiffeners of decks for helicopters with skids will be specially considered.

C 200 Plating and stiffeners

201 The thickness of deck plating subjected to wheel loading is not to be less than:

$$t = \frac{77.4 k_s \sqrt{k_w} b s p}{\sqrt{m \sigma}} \text{ (mm)}$$

$$k_s = 1.1 - 0.25 s/l$$

max. 1.0 for s/l = 0.4
min. 0.85 for s/l = 1.0

$$k_w = \frac{1.3}{\left(\frac{a}{s} + 1.8\right)^2}$$

max. 1.0 for a ≥ 1.94s.

p and A = as given in B200.

$$a = \text{extent in m of the load area parallel to the stiffeners}$$

(see Fig. 2)

$$b = \text{extent in m of the load area perpendicular to the stiffeners}$$

(see Fig. 2)

$$m = \frac{38}{\left(\frac{b}{s}\right)^2 - 4.7 \frac{b}{s} + 6.5}$$

The m-value is based on the assumption that b is smaller than s.

$$\sigma = 370 f_1 \text{ N/mm}^2 \text{ (landing condition)}$$

$$f_1 = \text{as given in Pt.3 Ch.1 Sec.2 B200.}$$

202 The section modulus for stiffeners subjected to wheel loading is not to be less than:

$$Z = \frac{1000 k_w l a b p}{m \sigma} \text{ (cm}^3)$$

$$k_w = 1.0 \text{ for } b/s \leq 0.6$$

$$= \left(1.15 - 0.25 \frac{b}{s}\right) \text{ for } 0.6 < b/s \leq 1.0$$

$$a = \text{extent in m of the load area parallel to the stiffener}$$

$$b = \text{extent in m of the load area perpendicular to the stiffener}$$

$$\sigma = \frac{\sqrt{2} A}{\text{unless otherwise specified}}$$

$$= \text{as given in B200}$$

$$m = \frac{r}{\left(\frac{a}{l}\right)^2 - 4.7 \frac{a}{l} + 6.5}$$

r = factor depending on the rigidity of girders supporting continuous stiffeners, taken as 29 unless better support conditions are demonstrated

= 38 when continuous stiffener may be considered as rigidly supported at each girdner.

The m-value is based on the assumption that a is smaller than l.

$$\sigma = 180 f_1 \text{ N/mm}^2 \text{ (landing condition).}$$

203 When the helicopter deck is designed and fabricated in sections, the following items are to be satisfactorily documented:

---connections between the sections are to have, at least, the equivalent strength as required for the continuous deck
---connections between the sections are to be demonstrated to have oil and fuel tightness (including burning fuel).
C 300 Girders and supporting structures

301 The scantlings are normally to be based on direct stress analysis. See Pt 3 Ch. 1 Sec. 5. The basic usage factor, $\eta_0$, is as follows:

- landing condition: $\eta_0 = 0.67$
- stowed condition: $\eta_0 = 0.80$

C 400 Welded aluminium decks

401 Upon special consideration the yield stress for unaffected zone may be used in the strength calculations provided the welds are placed at areas with low stresses.

Guidance note:
For rolled plates the yield stress for unaffected zone may be used in the plate thickness formula in 201, provided the distance between the stiffener and the plate butt weld parallel with the stiffener is approximately 0.25 s.

---end-of-Guidance-note---

C 500 Safety net

501 The helicopter deck is to be protected by a safety net at least 1.5 m wide. The outer edge is not to rise more than 0.15 m above the edge of the deck.

502 The strength of safety nets including inner and outer rails are to be tested for type approval or individual approval. The flexibility and tightening are to be chosen to avoid rebounding. The number and shape of rails and brackets are to be chosen to minimize injuries.

Guidance note:
In rails and brackets etc. supporting safety nets, allowable stresses in approximate static calculations according to B301 may be taken as given in 300.

---end-of-Guidance-note---

C 600 Tie-down points

601 The breaking load of the tie-down point(s) for helicopters calling at the unit are to be provided by the helicopter operator or manufacturer.

Tentative values:
- 50 kN
- $0.5 \times M_H$

$M_H$ as given in B201. Tie-down points located on helicopter decks are normally to be flush-fitting.
APPENDIX E

HELIDECK REQUIREMENTS

GERMANISHER LLOYD
Section 6

Helicopter Facilities

A. General Indications

1. This section summarizes the structural and fire protection/fire fighting considerations relating to helicopter landing facilities. Other safety aspects such as size, clearances (approach), accessibility, marking and lighting, drainage and safety net, will generally be covered by or treated according to relevant national regulations or codes.

2. Regarding the allocation of the helicopter facilities within the whole platform or installation arrangement, applicable national regulations shall be observed.

B. Structure

1. General

1.1 The helicopter landing area shall be dimensioned for the largest helicopter type expected to use the landing deck.

1.2 For scantling purposes, other loads (cargo, snow/ice, etc.) are to be considered simultaneously or separately, depending on the conditions of operation to be expected. Where these loads are not known, the data contained in 2. below may be used as a basis.

1.3 The following provisions shall in principle apply to landing areas on special, pillar-supported landing decks or on the upper deck, superstructure deck or deckhouse of a fixed or mobile installation. In the latter case, special safety considerations may be necessary.

2. Load conditions

The following load conditions (LC) are to be considered:

LC 1: Helicopter landing impact, with the following forces acting simultaneously:

a) Wheel or skid load $F$ applied at two points simultaneously, at an arbitrary (most unfavourable) position on the landing deck including the safety zone.

Distance "e" according to helicopter type to be expected.

\[ F = 0.75 \cdot W [kN], \text{ } F \text{ evenly distributed over contact area } A \]

\[ W = \text{maximum admissible take-off weight} \]

\[ A = 30 \cdot 30 \text{ cm}^2 \text{ for single wheel or according to data supplied by helicopter manufacturer; for dual wheels or skids, } A \text{ to be determined individually in accordance with given dimensions.} \]

b) Distributed load $p = 0.5 \text{ kN/m}^2$ (for taking into account snow or other environmental loads)

c) Weight of landing deck (for supporting structure)

d) Wind load in accordance with the wind velocity admitted for helicopter operation ($v_w$). Where no data are available, $v_w = 25 \text{ m/s}$ may be used.

Where the upper deck of a superstructure or deckhouse is used as a helicopter deck and the spaces below are normally manned (quarters, bridge, control room, etc.) the impact loading (a) is to be multiplied by a factor of 1.15.

LC 2: Helicopter lashed on deck, with the following vertical forces acting simultaneously:

a) Wheel or skid loads $F$ acting at two points resulting from the lashing position and distribution of the wheels or supports according to helicopter construction.

b) Weight of landing deck

c) Surface load $p = 2.0 \text{ kN/m}^2$ over the entire landing deck.

Vertical accelerations of the installation shall be accounted for where considered meaningful. If no relevant data are available, an acceleration factor of 1.5 should be applied for floating platforms.

LC 3: Helicopter lashed on deck, with the following horizontal (a to c) and vertical (d, e) forces acting simultaneously:
a) \( H = 0.6 \text{ W [kN]} \) applied at the points of support and distributed according to actual weight distribution.

b) (Weight of landing deck) \( \cdot 0.6 \)

c) Wind load taking into account the lashed helicopter and a deck cargo of an average height of 0.5 m; wind velocity (gust) to be taken according to local weather conditions; if no relevant data are available, \( \nu_w = 50 \text{ m/s} \)

d) \( F = 0.5 \text{ W [kN]} \)

e) Weight of landing deck

LC 3 to be considered only for floating installations. In case of fixed platforms the horizontal wind load (c) is to be accounted for in LC 2.

3. Scantlings of structural Members

3.1 Structural analysis shall be effected in accordance with Chapter 2, Section 3. Regarding construction and materials employed, see Chapter 2, Section 4.

3.2 Admissible stresses:
Axial and bending stress:
\[
\sigma_{adm} = \frac{R_{eh}}{\gamma_S}
\]

\( R_{eh} = \) minimum specified yield strength
(For aluminium, instead of \( R_{eh} \):
\( R_{p0.2} = 0.2 \% \) proof stress)

Compression (buckling):
\[
\sigma_{adm} = \frac{\sigma_{cr}}{\gamma_B}
\]

\( \sigma_{cr} = \) critical buckling stress

Safety factors \( \gamma_S \) and \( \gamma_B \) according to Table 6.1.

3.3 The scantlings of the plate panels may be determined using the following formula:
\[
t = c \sqrt{\frac{235}{R_{eh}}} + t_c \quad [\text{mm}]
\]

c = factor according to the following formulae:
for \( \frac{b}{a} \geq 2.5 \):
\[
c = 2.04 - \sqrt{\alpha(5.4 - 7.2\alpha)}
\]
for \( 0 < \alpha \leq 0.3 \)
\[
c = 1.21 - 0.50\alpha
\]
for \( 0.3 < \alpha \leq 1.0 \)

(Linear interpolation for intermediate values of \( b/a \))

\[
\alpha = \frac{A}{a \cdot b}
\]

\( a = \) shorter side of plate field (normally stiffener spacing)

\( b = \) longer side of plate field (\( b \) must not be assumed greater than 2.5 \( a \))

\( F_A = \) see 2. above; \( R_{eh} \) in N/mm²

\( t_c = \) corrosion allowance, depending on material, protection, service and maintenance conditions.

Table 6.1

<table>
<thead>
<tr>
<th>Safety factors</th>
<th>( \gamma_S )</th>
<th>( \gamma_B )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load condition</td>
<td>LC 1</td>
<td>LC 2</td>
</tr>
<tr>
<td>Type of element</td>
<td>LC 3</td>
<td>LC 1</td>
</tr>
<tr>
<td>Stiffeners (deck beams)</td>
<td>1.1</td>
<td>1.25</td>
</tr>
<tr>
<td>main girders (deck girders)</td>
<td>1.45</td>
<td>1.45</td>
</tr>
<tr>
<td>load-bearing substructure (pillar systems)</td>
<td>2.0</td>
<td>1.67</td>
</tr>
</tbody>
</table>

C. Fire Protection and Fire Extinguishing Systems

1. Fire protection

1.1 Helicopter decks are to be of steel or equivalent fire resistant construction.

If the space below the deck is a high fire risk space, the deck should be an "A 60" class division.

1.2 The helicopter deck shall be provided with at least two escape routes, which should be on opposite sides of the helicopter landing area.
1.3 The safe drainage of spilled fuel shall be provided for.

2. Fire extinguishing systems

On any helicopter deck there should be provided and stored near to the means of access to that deck:

- Dry powder extinguishers with a total capacity of not less than 45 kg.

- A suitable foam application system consisting of monitors or branch pipes. The system must be capable of supplying to the points of discharge 6 l/min of foaming agent per each square meter within a circle of diameter D for at least 5 minutes. D is the distance in meters across the main rotor and tail rotor in a fore and aft line of a helicopter with a single main rotor and across both rotors for a tandem rotor helicopter.

The operation of the foam system is not to interfere with the simultaneous operation of the fire main.

- CO₂ extinguishers of a total capacity of not less than 18 kg, one of the extinguishers to be so equipped as to reach the engine area of a helicopter using the platform.

- At least two dual purpose nozzles and hoses sufficient to reach any part of the helicopter deck.

- At least one fireman’s outfit.

See also Chapter 4, Section 10.

3. Fuel storage

3.1 The fuel storage area should be as remote as practicable from accommodation spaces, escape routes and embarkation areas, and suitably isolated from areas containing a source of ignition.

3.2 Containment of fuel spillage and draining to a safe location is to be provided for.

3.3 Tanks and associated equipment are to be protected against physical damage and from a fire in an adjacent space or area.

3.4 Storage tank fuel outlet valves are to permit closure from a remote position.

3.5 The fuel pumping unit is to be connected to one tank at a time and the piping between the tank and the pumping unit is to be of steel or equivalent fire resistant material, as short as possible and protected against damage.

3.6 Electrical fuel pumping units and associated control equipment are to be of a type suitable for the location and potential hazards.

Fuel pumping units should incorporate a device which will prevent over-pressure in the delivery or filling hose.

3.7 Where portable fuel storage tanks are used, special attention is to be given to

a) design of the tank for its intended purpose
b) mounting and securing arrangements
c) electrical bonding
d) inspection procedure.

3.8 Fire-extinguishing arrangements for the fuel storage area are not necessary, provided that monitors will cover this area. Otherwise a suitable water spraying or foam system is to be provided.

3.9 "NO SMOKING" signs are to be displayed at appropriate locations.

4. Electrical installations

For electrical installations on helicopter decks, see also Chapter 5, Section 14.
APPENDIX F

HELIDECK REQUIREMENTS

LLOYD’S REGISTER OF SHIPPING
Special Features

4.5 Pontoon deck plating

4.5.1 Where the pontoon is constructed of steel decking with stiffening webs, the deck plate thickness, t, is to be not less than that required by 3.4.

4.5.2 The plate thickness, t, for aluminum pontoons is to be not less than:

\[ t = (1.4t_1 + 0.75) \text{ mm} \]

where \( t_1 \) is the mild steel thickness as determined from 3.4.

For aluminum pontoons designed for the exclusive carriage of unladen wheeled vehicles:

\[ t = 1.4t_1 \text{ mm} \]

4.5.3 Where it is proposed to use plywood decking, the arrangement and thickness will be considered. Plywood alone, is not generally, to be used for axle loads in excess of 7.8 kN (0.8 tonne-m).

4.5.4 Attention is drawn to National fire regulations which in certain cases may ban the use of plywood and certain other materials in ‘special category spaces’ on passenger ships.

4.6 Pontoon webs and stiffeners

4.6.1 The section modulus of webs and stiffening of steel pontoons is to be not less than:

(a) For general purpose cargo decks where fork lift trucks may be used:

\[ Z = (0.375K_1P h + 0.00125K_2 h s l_d^2) \text{ k cm}^3 \]

(b) For decks designed for the carriage of vehicles only:

\[ Z = 1.30K_1P h k \text{ cm}^3 \]

where the values of \( K_1 \) and \( K_2 \) are given in Table 9.4.1, and

\[ h = \text{load height of cargo on the deck, where this is proposed to be carried, in metres} \]

\[ P = \text{total weight, in tonnes, of the vehicle divided by the number of axles. Where the distribution of weight is not uniform, } P \text{ is to be taken as the greatest axle load. For fork lift trucks the total weight is to be applied to one axle.} \]

### Table 9.4.1 Values of \( K_1 \) and \( K_2 \)

<table>
<thead>
<tr>
<th>Wheel spacing* (Beam span)</th>
<th>( K_1 )</th>
<th>( K_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>15.4</td>
<td>1.89</td>
</tr>
<tr>
<td>0.2</td>
<td>14.6</td>
<td>1.845</td>
</tr>
<tr>
<td>0.3</td>
<td>13.55</td>
<td>1.730</td>
</tr>
<tr>
<td>0.4</td>
<td>11.5</td>
<td>1.55</td>
</tr>
<tr>
<td>0.5 and greater</td>
<td>10.1</td>
<td>1.30</td>
</tr>
</tbody>
</table>

* Outer wheel to outer wheel on axles with multiple wheel arrangements

4.6.2 The section modulus of webs and stiffening of aluminum pontoons is to be not less than that defined in 4.6.1 replacing \( K \) by \( K_0 \) where \( K_0 \) is defined in Ch 2.1.

4.6.3 Where plywood decking is proposed, or in other arrangements where the decking is not integral with the stiffening webs, the arrangement of the gillage of webs is to be such as to provide the required strength.

4.7 Deflection

4.7.1 Where wheeled vehicles are to be used, the supporting arrangements are to be such that the movement at the edge of one pontoon relative to the next does not exceed 50 mm during loading or unloading operations.

4.8 Direct calculations

4.8.1 As an alternative to 4.3 to 4.7, the structure may be designed on the basis of a direct calculation using a gillage idealization. The method adopted and the stress levels proposed for the material of construction are to be submitted for consideration.

### Section 5

Helicopter landing areas

5.1 General

5.1.1 Where it is proposed to provide a helicopter landing area on the ship, the structure is to be designed to suit the largest helicopter type which it is intended to use.

5.1.2 Attention is drawn to the requirements of National and other Authorities concerning the construction of helicopter landing platforms and the operation of helicopters as they affect the ship.

5.1.3 Plans are to be submitted showing the proposed scantlings and arrangements of the structure. The type, size and weight of helicopters to be used are also to be indicated. Details of the helicopter types to be used are to be included in the Loading Manual (see Ch 4.8.2) and be contained in a notice displayed on the helicopter landing deck.

5.1.4 Where the landing area forms part of a weather or erection deck, the scantlings are to be not less than those required for decks in the same position.

5.2 Symbols

5.2.1 The symbols in this Section are defined in 1.2 and in the appropriate sub-Section.

5.3 Arrangements

5.3.1 The landing area is to be sufficiently large to allow for the landing and manoeuvring of the helicopter, and is to be approached by a clear landing and take-off sector complying in extent with the applicable Regulations.
5.3.2 The landing area is to be free of any projections above the level of the dock. Projections in the zone surrounding the landing area are to be kept below the heights permitted by the Regulations.

5.3.3 Suitable arrangements are to be made to minimize the risk of personnel or machinery sliding off the landing area. A non-slip surface and anchoring devices are to be provided.

5.3.4 Arrangements are to be made for drainage of the platform, including drainage of spill fuel.

5.4 Landing area plating

5.4.1 The deck plate thickness, \( t \), within the landing area is to be not less than:

\[ t = t_1 + 1.5 \text{ mm} \]

where

\[ t_1 = \frac{0.085}{1000} \text{ mm} \]

\( \alpha \) = thickness coefficient obtained from Fig. 9.3.1

\( \beta \) = tyre print coefficient used in Fig. 9.3.1

\[ \beta = \log_{10} \left( \frac{P_{\text{tyre}}^2}{60^2} \right) \]

The plating is to be designed for the emergency landing case taking

\[ P_1 = 2.5 P_0 \frac{\phi_0}{\phi_1} \gamma P_w \text{ tonnes} \]

in which \( \phi_1, \phi_0, \gamma_0 \) are to be determined from Table 9.3.1

\( P = \) the maximum all up weight of the helicopter, in tonnes

\( P_w = \) landing load, on the tyre print in tonnes;

for helicopters with a single main rotor, \( P_w \) is to be taken as \( P \) divided equally between the two main undercarriages;

for helicopters with tandem main rotors, \( P_w \) is to be taken as \( P \) distributed between all main undercarriages in proportion to the static loads they carry

\( \gamma = \) a location factor given in Table 9.5.1.

The tyre print dimensions specified by the manufacturer are to be used for the calculation. Where these are unknown it may be assumed that the print area is 300 x 300 mm and this assumption is to be indicated on the submitted plan.

5.4.2 The plate thickness for aluminium docks is to be not less than:

\[ t = 1.4t_1 + 1.5 \text{ mm} \]

where \( t_1 \) is the mild steel thickness as determined from 5.4.1.

5.4.3 For helicopters fitted with landing gear consisting of skids, the print dimensions specified by the manufacturer are to be used. Where these are unknown it may be assumed that the print consists of a 300 mm line load at each end of each skid, when applying Fig. 9.3.1.

5.5 Deck stiffening and supporting structure

5.5.1 The helicopter deck stiffening and the supporting structure for helicopter platforms is to be designed for the load cases given in Table 9.5.2 in association with the permissible stresses given in Table 9.5.3.

5.5.2 The minimum moment of inertia, \( I \), of aluminium secondary structure stiffening is to be not less than:

\[ I = \frac{5.25}{k_0} Z L \text{ cm}^4 \]

where \( Z \) is the required section modulus of the aluminium stiffener and attached plating and \( k_0 \) as defined in 4.6.2.

5.5.3 Where a grillage arrangement is adopted for the platform stiffening, it is recommended that direct calculation procedures be used.

5.6 Bimetallic connections

5.6.1 Where aluminium alloy platforms are connected to steel structures, details of the arrangements in way of the bimetallic connections are to be submitted.
### Table 9.3.1 Deck plate thickness calculation

<table>
<thead>
<tr>
<th>Symbols</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a, s, a, ) and ( v ) as defined in Fig. 9.3.1</td>
<td></td>
</tr>
<tr>
<td>( n ) = tyre correction factor, see Table 9.3.3</td>
<td></td>
</tr>
<tr>
<td>( P_1 ) = load, in tonnes, on the tyre print, for closely spaced wheels, the shaded area shown in Fig. 9.3.1 may be taken as the combined print</td>
<td>( P_1 = \phi_1 \phi_2 \phi_3 F_w )</td>
</tr>
<tr>
<td>( \phi_1 ) = corrected patch load, in tonnes</td>
<td>( \phi_1 = \frac{2n_1 + 1.5s}{n_1 + 1.5s} )</td>
</tr>
<tr>
<td>( \lambda ) = dynamic magnification factor</td>
<td>( \phi_1 = \frac{n_1}{s} )</td>
</tr>
<tr>
<td>( \phi_2 ) = patch aspect ratio correction factor</td>
<td>( \phi_2 = \frac{s}{\sqrt{\beta}} )</td>
</tr>
<tr>
<td>( \phi_3 ) = wide patch load factor</td>
<td>for ( a \geq 3.0 )</td>
</tr>
<tr>
<td></td>
<td>( \phi_3 = 1.0 )</td>
</tr>
<tr>
<td></td>
<td>( \phi_3 = 0.6 \frac{a}{s} + 0.4 ) for ( 1.5 \leq \frac{a}{s} \leq 1.0 )</td>
</tr>
<tr>
<td></td>
<td>( \phi_3 = 1.2 \frac{a}{s} ) for ( \frac{a}{s} \geq 1.5 )</td>
</tr>
</tbody>
</table>

### Notes:
- \( \lambda = 1.25 \) for harbour conditions
- \( \phi_2 = (1 + 0.7\%a) \) for sea-going conditions

#### Fig. 9.3.1 Tyre print chart

- \( s \) and \( a \) are panel dimensions, in mm
- \( u \) and \( v \) are print dimensions, in mm

N.B.: For intermediate values of \( \phi_2 \) linear interpolation may be used.
APPENDIX G

STEEL DECKS – GRAPHICAL PRESENTATION OF COMPARISONS BETWEEN EXPERIMENTAL RESULTS AND CLOSED-FORM PREDICTIONS

Figures F.1 to F.26 present comparisons in graphical form between:

- experimental load-deflection curves from Jackson and Frieze, obtained by extracting appropriate points of the curves presented in Figure 3;
- empirical approximations to these curves based on Hughes' multiple-regression fit;
- point estimates of the panel capacities using the formulations of the Certifying Authorities of DNV, GL and LRS with all safety factors removed.

The loads and deflections are presented in normalised form of $C_p$ versus $C_{sp}$. The load parameter $C_p$ is defined in Section 5 while the deflection parameter $C_{sp} = w_p / t$, $w_p$ being the permanent set resulting from the application of the load equivalent to $C_p$. 
Figure F.1
Model JF1: Comparison of load capacities and load–deflection responses

Figure F.2
Model JF2: Comparison of load capacities and load–deflection responses

Figure F.3
Model JF3: Comparison of load capacities and load–deflection responses
Figure F.4
Model JF4: Comparison of load capacities and load–deflection responses

Figure F.5
Model JF5: Comparison of load capacities and load–deflection responses

Figure F.6
Model JF6: Comparison of load capacities and load–deflection responses
Figure F.7
Model JF7: Comparison of load capacities and load-deflection responses

Figure F.8
Model JF8: Comparison of load capacities and load-deflection responses

Figure F.9
Model JF9: Comparison of load capacities and load-deflection responses
Figure F.10
Model JF10: Comparison of load capacities and load-deflection responses

Figure F.11
Model JF11: Comparison of load capacities and load-deflection responses

Figure F.12
Model JF12: Comparison of load capacities and load-deflection responses
Figure F.13
Model JF13: Comparison of load capacities and load–deflection responses

Figure F.14
Model JF14: Comparison of load capacities and load–deflection responses

Figure F.15
Model JF15: Comparison of load capacities and load–deflection responses
Figure F.19
Model JF19: Comparison of load capacities and load–deflection responses

Figure F.20
Model JF20: Comparison of load capacities and load–deflection responses

Figure F.21
Model JF21: Comparison of load capacities and load–deflection responses
Figure F.22
Model JF22: Comparison of load capacities and load–deflection responses

Figure F.23
Model JF23: Comparison of load capacities and load–deflection responses

Figure F.24
Model JF24: Comparison of load capacities and load–deflection responses
Figure F.25
Model ZA: Comparison of load capacities and load-deflection responses

Figure F.26
Model ZB: Comparison of load capacities and load-deflection responses