Common Structural Rules for Bulk Carriers, January 2006

Background Document

CHAPTER 7 – DIRECT STRENGTH ANALYSIS

NOTE:

- This TB is published to improve the transparency of CSRs and increase the understanding of CSRs in the industry.
- The content of the TB is not to be considered as requirements.
- This TB cannot be used to avoid any requirements in CSRs, and in cases where this TB deviates from the Rules, the Rules have precedence.
- This TB provides the background for the first version (January 2006) of the CSRs, and is not subject to maintenance.

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TABLE OF CONTENTS:

SECTION 1 – DIRECT STRENGTH ASSESSMENT OF PRIMARY SUPPORTING MEMBERS

1 GENERAL

1.1 Application

1.1.1

1.1.1.a Chapter 7 describes the calculation methods for direct strength assessment of bulk carriers. The three types of analysis required by CSR and given below are mentioned in the rules, but only the description common to the three types of analysis in Section 1 is given here.

1.1.2

1.1.2.a The analysis required in Sec.2 will give the scantling of primary supporting members, the sec.3 is for the local reinforcement of stress concentration area and the analysis of Sec. 4 is for the calculation of fatigue damage factors.

1.2 Computer program

1.2.1

1.2.1.a A program with adequate reliability including not only a solver for FEA but also a pre/post processor should be used because scantlings will be increased/decreased according to the results of direct strength assessment. However, since rules do not approve or specify any program in particular, a statement such as the above has been made.

1.3 Submission of analysis report

1.3.1

1.3.1.a Some of data can be submitted as electric style such as application data for used Pre-post processor or CAE application.

1.4 Net scantling

1.4.1

1.4.1.a The corrosion amount given in Chapter 3 is the maximum expected value by which the thickness is considered to decrease during the design life of a ship. Deducting the required wastage amount from all the members of the hold model used was considered excessive; it was considered more appropriate to deduct the average wastage amount. The average wastage amount was set as half the required amount, and it was decided as the deduction amount for the model.

However, 100% corrosion in each panel is fairly appropriate when determining the critical buckling stress, and therefore, the corrosion deduction is taken as 100% in this case.

1.5 Applied loads

1.5.1 Design loads

1.5.1.a Applicable loads will be calculated according to the formulae in Ch. 4. Actual combination of design load and loading condition are described in Appendixes of Ch. 4.

1.5.2 Structural weight

1.5.2.a The hull structure inertia force by dynamic acceleration is not considered FEA.

1.5.3 Loading conditions

1.5.3.a Actual loading cases to be applied are described in Appendixes of Ch. 4.

SECTION 2 – GLOBAL STRENGTH FE ANALYSIS OF CARGO HOLD STRUCTURES

1 GENERAL

1.1 Application

1.1.1

1.1.1.a Coarse mesh analysis is performed with the aim of deciding the scantlings (plating thickness) of primary parts of primary structural members. Studies on the bearing strength to withstand fatigue collapse and details of partial reinforcements will be carried out in the detailed stress assessment of Section 3 or the hot-spot stress analysis for fatigue strength assessment of Section 4.

1.1.2

1.1.2.a The requirements show that the CSR set the three criteria, yield, buckling and deformation. Finally, designer should clearly show that the scantling of the ship are clear all criteria.

2 ANALYSIS MODEL

2.1 Extent of model

2.1.1

2.1.1.a Since the past, conditions of symmetry at both ends of the model were introduced in the 1/2+1/2 or 1/2+1+1/2 hold length model and boundary conditions were used so as to support bulkheads in the direct calculation of bulk carriers. Analysis using such modeling extent and boundary conditions has the following issues:

(1) Bulkhead stress condition must be analyzed correctly since bulkhead parts are also subject to strength assessment in the common rules. However, large support reactions are generated in bulkheads with the boundary conditions used for bulkhead support.

(2) Since bulkheads are supported, stress components due to hull girder loads that were being ignored until now can no longer be ignored because stresses that include hull girder loads are now being calculated and assessed. Hull girder loads due to design loads applied in the boundary conditions until now cannot be calculated easily.

(3) In the past, the 1/2 hold length part was also assessed by introducing conditions of symmetry. However, the centers of the hold (in the longitudinal direction) and the double bottom may be offset because of the effect of the stool (often extends over 1 transverse spacing) installed at the lower part of the bulkhead, and the stress condition of the double bottom, which is important, may not be analyzed correctly.

Considering these issues, the modeling extent in CSR has been taken as 3 holds. The central hold and the bulkheads forward and aft of it are the extent of assessment, and the supports at the bulkheads to be assessed are eliminated.

2.1.2

2.1.2.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.1.3

2.1.3.a Generally, all structure members that will be assessed by the requirements of CSR should be modeled. Stiffeners on outer and inner shell or watertight wall should be modeled since these elements will transfer the pressure to supporting structure.

2.2 Finite element modeling

2.2.1

2.2.1.a The types of finite elements used in the model are described here. The analysis of holds of bulk carriers performed conventionally is clarified.

Regulation has been established for using two-dimensional anisotropic elements. The method for performing analysis of rigidity of longitudinals including plating has been approved.

2.2.2

2.2.2.a Since stiffeners will be boundary condition of buckling panel in buckling strength assessment, mesh boundaries are to simulate the stiffening system. If mesh boundaries do not coincide to actual stiffening systems, stresses can be modified according to Appendix 2 of this Chapter.

2.2.3

2.2.3.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.2.4

2.2.4.a The criteria value of yield strength is decided considering the mesh size which described in the requirement.

Primary supporting members in double bottom or double hull system are divided into three elements heights since stress due to bending of the double hull/bottom structure will be clearly shown in the model.

Considering the accuracy of the analysis, aspect ration of each shell elements should be less than 4 as far as practicable. Aspect ratio more than 4 can be acceptable for the elements not to be stress evaluated.

2.2.5

2.2.5.a The requirements describe for the orthotropic elements.

2.3 Boundary conditions

2.3.1

2.3.1.a The support conditions were set for both ends of the model as shown in the Fig.1. The model will be simply supported at both end and hull girder stress will be modified superimposing to element stress or applying hull girder force at both ends.

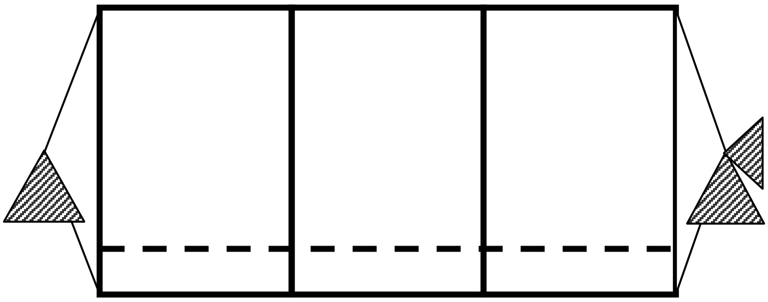

Fig. 7.1 Support condition for hold model

2.4 Loading conditions

2.4.1 General

2.4.1.a The loading conditions to be applied for global analysis are described in Chapter 4 Appendix 2.

2.5 Consideration of hull girder loads

2.5.1 General

2.5.1.a Hull girder loads are considered for each loading condition, but two kinds of analysis are required by this regulation for combining bending and shear loads: bending moment analysis where bending moment is the primary component and shear analysis where shear load is the main component.

The hull girder loads are required to be adjusted during bending moment analysis such that the bending moments occurring in the model at the center of the target hold become target values, and during shear analysis such that the shear loads of the model at the position of either the forward or aft bulkhead become target values.

Hull girder loads occurring in the model are calculated assuming that the model is a beam simply supported at both ends. Refer to the requirement of 2.5.4 of the Rules.

2.5.2 Vertical bending moment analysis

2.5.2.a The analysis considers only still water and wave bending moments. No shearing force except shearing force due to local loads that are applied to the extent of the model will be considered.

The combination of MS and MW for each load case is shown in the Appendix 2 of Chapter 4.

2.5.3 Vertical shear force analysis

2.5.3.a The shearing force analysis is required only for the case that the sharing force will be dominant, such as heavy ballast or alternate loading. Bending moment should be considered in spite of no shearing force considering in bending moment analysis, but not full.

2.5.4 Influence of local loads

2.5.4.a The formulae of bending moment and shearing force by local load are calculated using a simple beam theory. Sign conventions coincide to Ch4. Sec.3 [1.1.1].

2.5.5 Methods to account for hull girder loads

2.5.5.a CSR specifies either of two methods to perform analysis - the "superimposition method" that calculates stresses for assessment by superimposing the results of analysis by local loads only with the hull girder stresses, and the "direct method" in which adjusting loads (mainly bending moment) are applied to both ends of the model before the analysis so that the required bending moment is obtained at the considered position.

Discussions were held in IACS on the adoption of both methods to CSR. It was concluded that the actual results until now should be considered. Trial calculation results of both methods have shown no difference in the required plating thickness. Therefore, both superimposition method and indirect method were approved for adoption in the CSR for bending moment analysis.

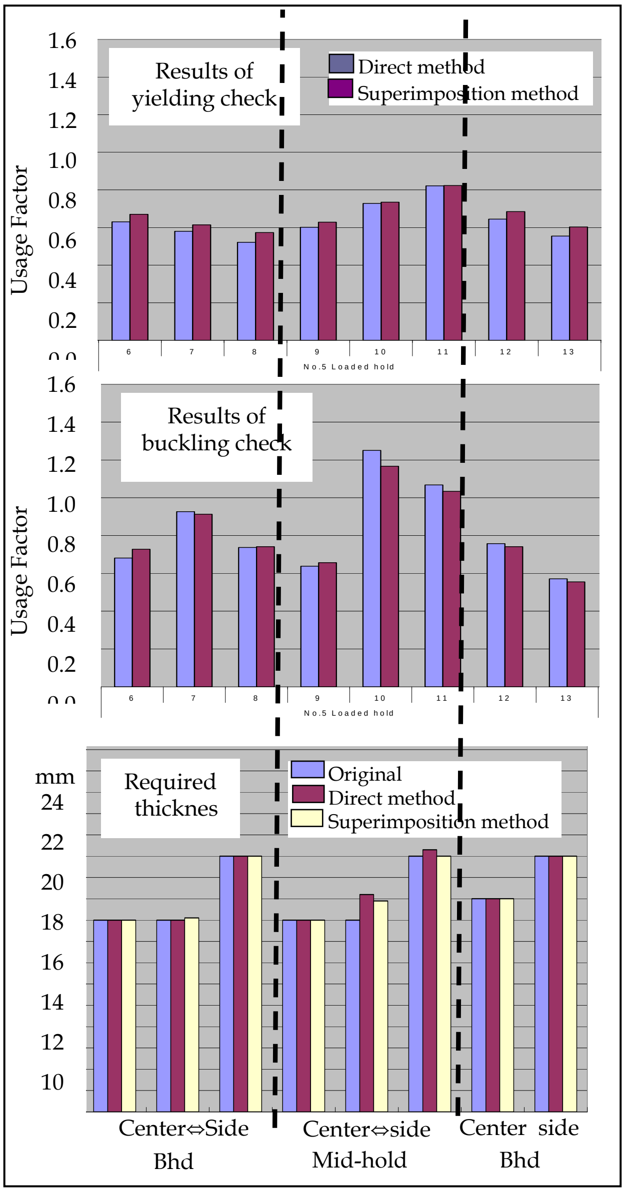

Fig. 7.2 Results of comparison of required plating thickness by direct method and by superimposition method

Fig. 7.2 shows the comparison of results calculated by the direct method and the superimposition method for ballast holds in existing double side skin Capesize BC. The assessment factor (usage factor: designed value/permissible value) varies slightly in the two methods; however, when the required plating thickness was determined, it was seen that this difference was within 0.5 mm.

It is required to perform shear analysis only by the direct method.

2.5.6 Direct method

2.5.6.a The bending moments which will apply to the both ends of the model will lead based on the simple beam theory.

2.5.7 Superimposition method

2.5.7.a Hull girder stress will be superimposed to the assessed stress at stress evaluation. The stress is calculated based on the beam theory and considering only hull girder bending moment. The moment is considered specified target moment and moment due to local loads applied to the model.

3 ANALYSIS CRITERIA

3.1 General

3.1.1 Assessment holds

3.1.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

3.1.2

3.1.2.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

3.2 Yield strength assessment

3.2.1 Reference stresses

3.2.1.a

3.2.2 Equivalent stress

3.2.2.a

3.2.3 Allowable stress

3.2.3.a The permissible value was taken as the yield strength of the material because the design loads were considered for the severest conditions of operation in a 25-year period in the North Atlantic route. In case of high tensile steel, it was decided to correct the permissible value using the material constant so that the permissible value was not the yield strength of material but a value smaller than that because the fatigue strength does not change for mild steel and because stress may increase with the increase in deformation.

The permissible value when anisotropic elements were used was set referring to the values of criteria of classification societies with experience of using the same elements.

3.3 Buckling and ultimate strength assessment

3.3.1 General

3.3.1.a

3.3.2 Stress of panel

3.3.2.a The regulation for buckling and ultimate strength in Section 3 Chapter 6 applicable to the hold FEA results have been developed in the first place, as a regulation applicable to results of analysis by frame element model. In frame analysis, even if members corresponding to flanges, such as in the double bottom are continuous, the increase in stress due to the Poisson effect occurring from flange continuity is not included because the floor or girder has been modeled as a single frame.

On the other hand, in the CSR analysis method, stress increase due to the Poisson effect in FEA of plating elements is included. For this reason, the FEA method becomes more severe if the analysis results according to this chapter are applied as-is to buckling and ultimate strength of Section 3, Chapter 6 if the same safety factor is used. It was therefore decided to use the criteria in Section 3, Chapter 6 after performing the correction of excluding the Poisson effect from the FEA results. The correction is to be limited only to cases where stress increases due to the Poisson effect. Therefore, it is applicable only when the two axial stresses in a panel are both compressive stresses.

3.3.3 Boundary conditions

3.3.3.a

3.4 Deflection of primary supporting members

3.4.1

3.4.1.a According to this regulation, adequate rigidity can be given to the double bottom structure by restricting the depth in 6.1.3, Section 6, Chapter 3. However, it was decided to control the relative deflection of the double bottom according to the FEA results with the aim of confirming adequate rigidity from the results of hold analysis. Fig. 7.2 shows the relative deflection ($\delta max/li$) of the double bottom structure obtained from analysis results based on CSR for conventional ships.

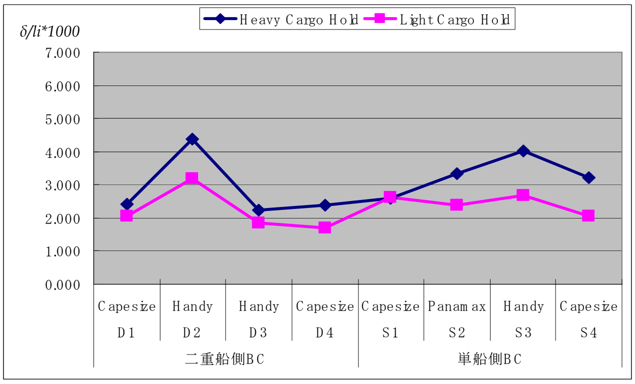

Fig. 7.2 Relative deflection of double bottom of existing ships according to common rules

SECTION 3 – DETAILED STRESS ASSESSMENT

1 GENERAL

1.1 Application

1.1.1

1.1.1.a The detailed analysis described in this section is implemented mainly to study the need for partial reinforcements.

2 ANALYSIS MODEL

2.1 Areas to be refined

2.1.1

2.1.1.a The purpose of detailed analysis is to confirm the strength of cross section of primary support members. When the global hold analysis is carried out using isotropic element with longitudinally frame space size mesh, detailed FEA will be required for the higher stressed case only due to the mesh size relatively small.

2.1.2

2.1.2.a In case orthotropic elements used, detailed analysis according to the section is mandatory since mesh size is larger than isotropic elements.

2.2 Refining method

2.2.1

2.2.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.3 Modeling

2.3.1 Element type

2.3.1.a Orthotropic elements cannot be used due to detailed analysis.

2.3.2 Mesh

2.3.2.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.4 Loading conditions

2.4.1

2.4.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.5 Boundary conditions

2.5.1

2.5.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

2.5.2

2.5.2.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

3 ANALYSIS CRITERIA

3.1 Allowable stress

3.1.1

3.1.1.a Detailed stress assessment requires the use of meshes having sizes of about one-fourth the longitudinal space in the overall assessment analysis of cargo holds. The results of actual detailed assessment of trial ships showed that the stress in the fine mesh parts was about 1.2 times the stress in coarse mesh analysis. Thus, the permissible stress for mild steel was specified as 1.2 times 235 N/mm^2, that is, 280 N/mm^2.

SECTION 4 – HOT SPOT STRESS ANALYSIS FOR FATIGUE STRENGTH ASSESSMENT

1 GENERAL

1.1 Application

1.1.1

1.1.1.a Very fine mesh analysis is performed to evaluate directly the hot spot stress for fatigue strength assessment.

1.1.2

1.1.2.a Standard loading conditions to be considered in fatigue strength assessment is referred to Appendix 3, Chapter 4 of the Rules.

2 ANALYSIS MODEL

2.1 Modeling

2.1.1

2.1.1.a Since it is necessary to assess hot spot stress which represents the stress concentration due to structural discontinuity for the fatigue assessment, it is preferable to evaluate hot spot stress by the model where a very fine mesh is mounted in the global cargo hold model.

2.1.2

2.1.2.a Since the stress concentration due to structural discontinuity depends on the surrounding structural arrangements, area where a very fine mesh is mounted is to be extended so that the effect of surrounding structural arrangements on stress concentration can be represented.

2.1.3

2.1.3.a Since the stress concentration due to structural discontinuity is remarkable in the local area, the size of very fine mesh is to be determined so that the behavior of stress concentration can be represented. The standard size of vary fine mesh is referred to the Guidance of IIW (Fatigue Design of Welded Joints and Components).

2.2 Loading conditions

2.2.1

2.2.1.a Referred to Appendix 3, Chapter 4 of the Rules.

2.2.2

2.2.2.a Referred probability level of the assessed stress response is determined so that the realistic stress can be assessed.

2.3 Boundary conditions

2.3.1

2.3.1.a Refer to 2.3 of Section 2, Chapter 7.

3 HOT SPOT STRESS

3.1 Definition

3.1.1

3.1.1.a Since most of the fatigue life is occupied by the crack initiation life, surface stress at a hot spot is to be assessed.

3.1.2

3.1.2.a Hot spot stress used in the fatigue assessment should include all of the load components. The hull girder stress is to be superimposed when the hot spot stress is assessed according to the superimposition method.

3.2 Evaluation of hot spot stress

3.2.1

3.2.1.a Hot spot stress is obtained using a linear extrapolation based on the stress located at 0.5 times and 1.5 times the plate thickness so that the effect of abrupt stress increase near the intersection of shell elements can be excluded.

3.2.2

3.2.2.a The hot spot stress is obtained linearly extrapolating the surface stress to the position of node of shell elements. In this case, especially in the case of right angle, evaluated stress tends to be overestimated. Degree of overestimation is mainly depending on the difference between the actual hot spot location and assumed location and the difference of surface stress gradient depending on the angle between two plates. Especially in the case of right angle, degree of overestimation is remarkable since a steep stress gradient is observed. Therefore, the correction factor for the hot spot stress evaluated by the shell elements FE analysis was examined based on the results of solid elements EF analysis.

3.2.3

3.2.3.a Stress evaluated by the shell element is generally represented by the stress at center of the element. When assessing the stress along free edge of non-welded area, these stresses evaluated by the shell element FEA are to be extrapolated to the evaluation point.

3.3 Simplified method for the bilge hopper knuckle part

3.3.1

3.3.1.a To assess hot spot stress, evaluation by multiplying the nominal stress with the stress concentration factor is an alternative method other than the evaluation according to the very fine FEA.

3.3.1.b To assess hot spot stress, evaluation by multiplying the nominal stress with the stress concentration factor is an alternative method other than the evaluation according to the very fine FEA.

3.3.2

3.3.2.a In order to apply stress concentration factor, the nominal stress at hot spot location is necessary to define. The definition of nominal stress at hot spot location is defined according to the results of global hold FEA. Refer to the Section 2, Chapter 7.

3.3.3

3.3.3.a Stress concentration factors applicable to the hot spot at an intersection of plates such as the bilge knuckle structure, the lower stool structure etc., which are the typical structural details to be fatigue assessed, were examined based on the theoretical solution and the results of FEA.

3.3.3.b The geometrical stress concentration depends on the differences of structural details. The effects of some typical cases of structural detail on the degree of stress concentration were evaluated according to the results of FEA to introduce the correction factors depending on the difference of structural details.

APPENDIX 1 – LONGITUDINAL EXTENT OF THE FINITE ELEMENT MODELS

1 LONGITUDINAL EXTENT

1.1

1.1.1

1.1.1.a Refer to Chapter 7 Sec.2 2.1.

2 TYPICAL MESH

2.1

2.1.1

2.1.1.a It is considered that for this topic, no information in addition to that shown in the Rules is necessary to explain the background.

APPENDIX 2 – DISPLACEMENT BASED BUCKLING ASSESSMENT IN FINITE ELEMENT ANALYSIS

1 INTRODUCTION

1.1

1.1.1

Information obtained from a finite element calculation cannot always be used directly for buckling analyses, as the subdivision of the finite element does not necessarily account for the buckling demands. Appropriate stresses and edge stress ratios must be evaluated for the buckling panel.

2 DISPLACEMENT METHOD

2.1 General

2.1.1.a In the FE-technique the stresses of a plane stress element is described by the displacements of the nodal points of that element. This leads to the idea to get the stresses of a buckling panel from the displacements of the corner nodes. The stresses in the buckling panel then can be evaluated for any location within the panel according to the shape function used. A suitable stress-displacement relationship is given in [PRZ] page 92.

With this stress information the buckling strength can be assessed as stated in Section 3, 3. "Buckling Criteria of Elementary Plate Panels".

Full numerical accuracy of displacements must be used, as the stresses result from differences of nodal displacements.

To obtain background information about finite Element techniques, reference is made to the following Literature:

[PRZ] J. S. Przemieniecki, "Theory of Matrix Structural Analysis", McGraw-Hill, Inc. 1968

[ZIE] O. C. Zienkiewicz, "The Finite Element Method", 3rd Edition, McGraw-Hill Book Company (UK) Ltd., 1977

[BAT] K. J. Bathe, "Finite Elemte Procedures ", Prentice Hall, 1995

2.1.2 4-node and 8-node panels

2.1.2.a The stresses obtained by the shape function of a 4-node plane stress element are only a coarse representation of the real stress distribution in a plate panel. It is considered to be sufficient, if the aspect ratio of the plate panel is not too big (i.e. less than 3) and the stress variation is moderate. In an 8-node panel the stress variation in longitudinal direction can be calculated more reliable.

2.1.3 Calculation of nodal displacements

2.1.3.a If a node of the buckling panel is located on the edge of a plane stress element, then its location can be described by:

$$\vec{r} = (1-\alpha)\vec{r}_i + \alpha\vec{r}_j \qquad \text{(a.1)}$$

and the corresponding displacement follows the same formula:

$$\vec{d} = (1-\alpha)\vec{d}_i + \alpha\vec{d}_j \qquad \text{(a.2)}$$

where

$\vec{r}$ = node of the buckling panel, $\vec{r}_i, \vec{r}_j$ = nodes of the plane stress element,

$\vec{d}$ = displacement at $\vec{r}$, $\vec{d}_i, \vec{d}_j$ = displacements at $\vec{r}_i, \vec{r}_j$,

α = interpolation factor in the interval [0,1]

2.1.3.b If a node of the buckling panel is located inside of a plane stress element, then its location can be described by:

$$\vec{r} = (1-\beta)[(1-\alpha)\vec{r}_i + \alpha\vec{r}_j] + \beta[(1-\alpha)\vec{r}_l + \alpha\vec{r}_k] \qquad \text{(b.1)}$$

and the corresponding displacement follows the same formula:

$$\vec{d} = (1-\beta)[(1-\alpha)\vec{d}_i + \alpha\vec{d}_j] + \beta[(1-\alpha)\vec{r}_l + \alpha\vec{r}_k] \qquad \text{(b.2)}$$

where the indices i, j, k, l refer to the F.E. nodes, in circular notation.

α, β = interpolation factors, both in the interval [0,1]

Equations a.1 and b.1 are used to determine α, β , and then the displacement can be received using b.1 and b.2 respectively.

2.1.4 Transformation in local system

2.1.4.a For the transformation of displacements from the global FE-system into the local system of the buckling panel apply to standard FE-literature, e.g.[Zie] page 333 ff.

2.2 Calculation of buckling stresses and edge stress ratios

2.2.1

2.2.1.a It is considered that for this topic, no information in addition to that shown in the CSR for Bulk Carriers, is necessary to explain the background.

2.2.2 4-node buckling panel

2.2.2.a The stress displacement matrix is obtained from the relation given in [PRZ] page 92, evaluated at the corner points. Owing to the stress convention for buckling stresses, the sign is changed, to receive positive compressive stresses.

The stress modification to contribute for the poisson effect is commented in 3.2.3.a

2.2.3 8-node buckling panel

2.2.3.a The stress displacement matrix is obtained from the relation given in [PRZ] page 92, evaluated at the corner points and the mid-points of the longer edges. Owing to the stress convention for buckling stresses, the sign is changed, to receive positive compressive stresses. The stress modification to contribute for the poisson effect is commented in 3.2.3.a