# Double Hull Tanker Structures
## – Some Practical Considerations about CSR Application

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**CSR brought us heavier hull steel weight,**
**and accordingly increased safety level.**

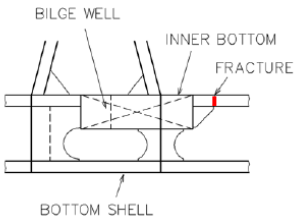
**Did the safety level increase in proportion to the hull steel weight increase?**

Contents

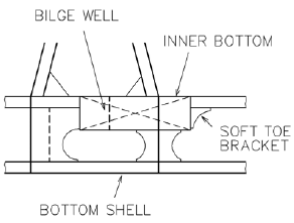
## Typical Damage in way of Bilge Well Structure (Bulk Carrier)

**Guidelines for the Inspection and Maintenance of Double Hull Tanker Structures - by Tanker Structure Co-operative Forum**

**Typical Damage**




**Proposed Repair**

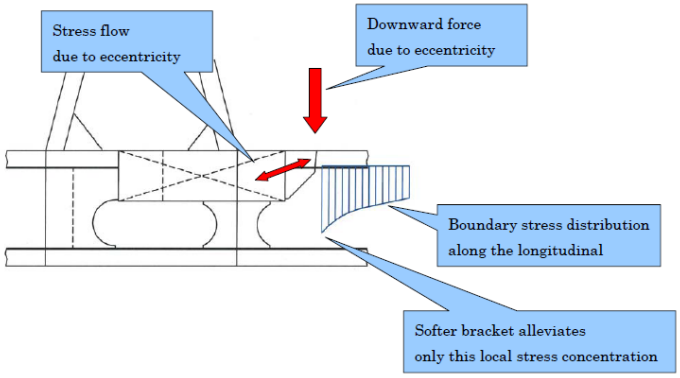



Factors contributing to damage

1. Stress concentration due to unsuitable bracket shape
2. Asymmetrical sectional shape of inner bottom longitudinal



## What is happening actually?




The longitudinal stress due to longitudinal bending exerts downward force to pull down the longitudinal stiffener at the bracket toe, inducing additional bending moment to the longitudinal stiffener.

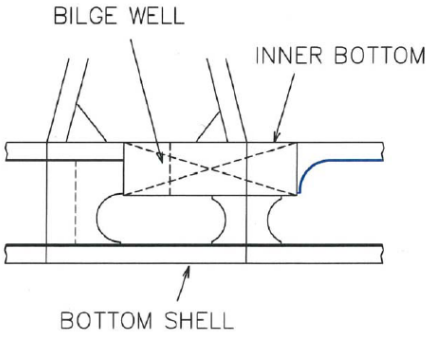
## Example of Countermeasure

Therefore, depending on:

- the ratio of the stiffener depth to the bilge well depth
- the magnitude of longitudinal bending stress in way

softer bracket toe and T-type longitudinal may not be a fundamental solution to avoid this type of cracks.

In some severer cases, structural modifications with integral bracket as shown right may be necessary.

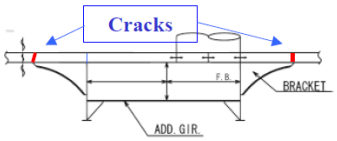


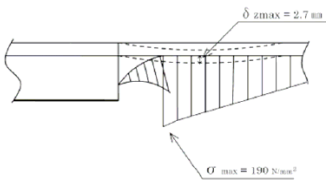



## Damage Example of Partial Upper Deck Girder

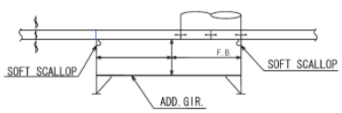
Similar damages can sometimes be observed in way of the underneath reinforcement for hose handling cranes.

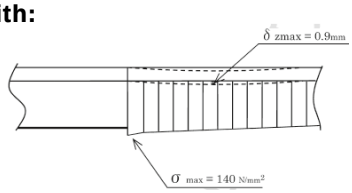
**The bracket is already soft enough ⇨ No room to reduce stress concentration!**




**When the brackets are dispensed with:**

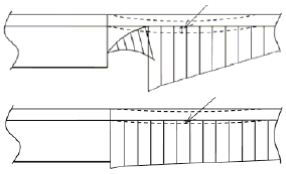


## Abrupt Change of Depth of Longitudinally Successive Girder / Stiffener

**Addition of reinforcing members does not always enhance strength !!**

CSR-O/T (Section 8, 1.6.5):
Suitable scarphing arrangement are to be made to ensure continuity of strength and the avoidance of abrupt structural changes.



CSR : Prescriptive, requires thicker scantling in general

Suitable structural configuration can be selected, going beyond rule requirements, but made possible only by:

✓Experienced designers' insight into the structural behavior

✓Experience shipyards' know-how, which is usually compiled in thousands of pages of hull structural design standards

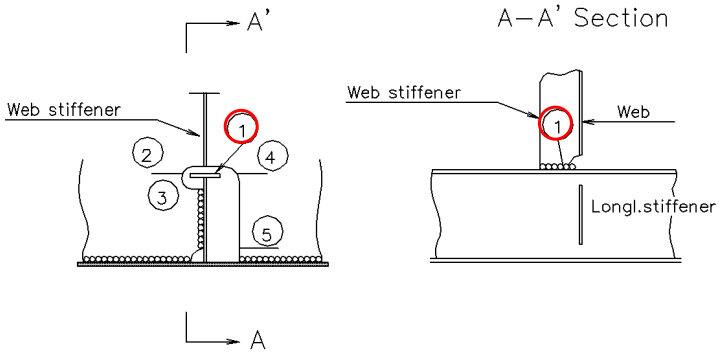


## Damage of Slot Cut-out (1st Generation)

1st generation cracks (around 1970's ~)

✧Most common cracks were at the root of the web stiffner (①)

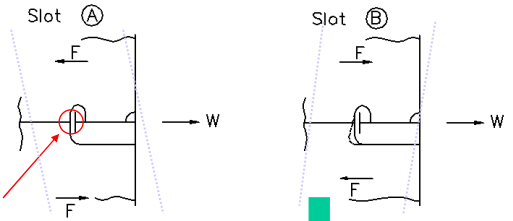
✧In some cases accompanied by other cracks



## Damage of Slot Cut-out (1st Generation)

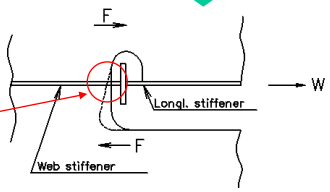
Two load elements acting at the connection between primary and secondary members:

- *W*: from longitudinals
- *F*: from shear force on primary member




Shear force F exerts compression

Shear force F exerts tension



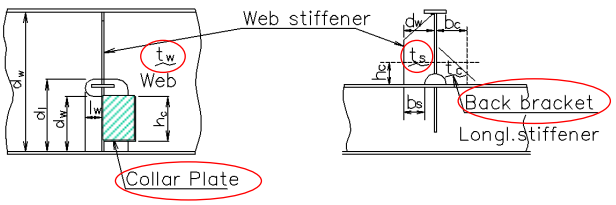

Action of Shear Force to Slot Cut-out



## Damage of Slot Cut-out (1st Generation) - Countermeasures

1. **to reduce stress due to W**
   - **to increase $t_w$, $t_s$, $d_w$, etc. or add backing bracket – stress is reduced in accordance with the nominal sectional area given.**
2. **to reduce stress due to F**
   - **to add collar plate to equilibrate shear forces from the both sides.**
3. **to make stresses from W and F to cancel each other**
   - **to change the slot cut-out direction, if construction process permits.**

A–A' Section



## Damage of Slot Cut-out (1st Generation)

Just for reference:

The direction of slot cut-out vulnerable to buckling is also vulnerable to fatigue due to the tensile stress at the root of the web stiffener.

We can kill two birds with one stone by proper direction of slot cut-out.

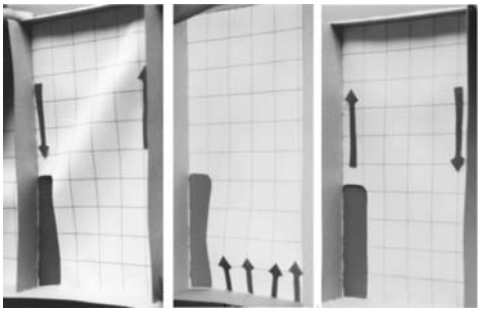


**Photo from "Design of Ship Hull Structures – A Practical Guide for Engineers" by Okumoto et al., Springer (2009)**

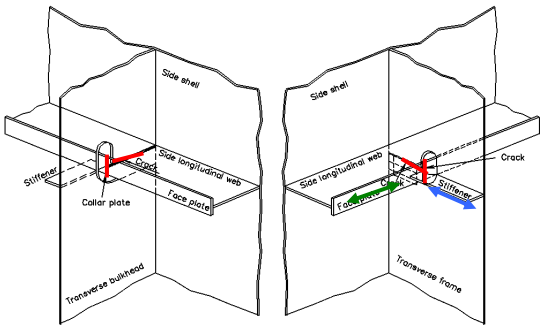


## Damage of Slot Cut-out (2nd Generation)

2nd generation cracks (1990 ~)

Characterized by the propagation into the longitudinal stiffeners

(especially side longitudinals in the vicinity of LWL)




(a)Side longitudinals crack at transverse bulkhead

(b)Side longitudinals crack at transverse frame

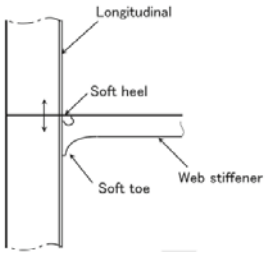
Stress in blue color was dominant for 1st generation cracks.

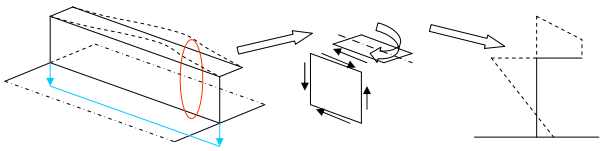
Relatively increased stress in green color brought 2nd generation cracks.

## Damage of Slot Cut-out (2nd Generation)

**Countermeasure: to decrease stress of longitudinal stiffener**

1. **By increased scantling of longitudinal**
2. **L-shaped longl. → T-shpaed longl.**
3. **Soft heel and toe of web stiffener**



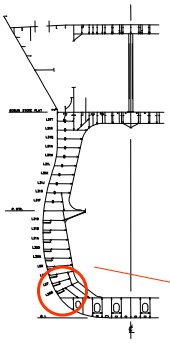
Lateral bending of face plate

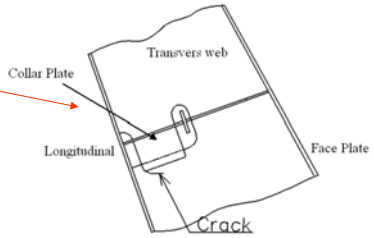
Shear stress at connection

Bending stress in section



## Damage of Slot Cut-out (3rd Generation)

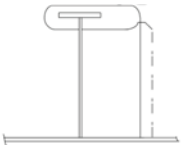




## Damage of Slot Cut-out (3rd Generation)

ROOT CAUSE 1: Combination of

- Large shear stress variation on the primary member web
- Tensile static stress at connection between the collar plate and primary supporting member web.



COUNTERMEASURE: In this case, softly shaped collar plate, attaching skin plate is an effective countermeasure. Arrangement of large web stiffener does not work to reduce this stress, caused by primary member shear.

ROOT CAUSE 2: Frequent loading-unloading cycles in shuttle service

Especially in case of longitudinal stiffener without web stiffener connection, where relatively higher stress around the slot is exerted by the loading from the longitudinals.

COUNTERMEASURE: We should be careful that softly shaped collar plate is not so effective against the load from the longitudinals. Effective countermeasure is simply to add web stiffeners, and to carry out adequate fatigue strength evaluation against the relevant loading-unloading cycles.



## Review of Slot Rules in CSR-O/T

Slot Strength Requirement in CSR-O/T (1/3)

- Section 4, 3.4.3 Connection between primary support members and intersecting stiffeners
  - Stipulated with regard to the direct stress in way of the web stiffener, and the shear stress in way of the shear connection including the collar plates. Only the load from the longitudinals is accounted for, and the shear forces on the primary member web is not considered.
  - That is, among the three countermeasures for the 1st generation cracks, only the first “most direct” countermeasure is accounted for. Shear force on the primary member is not taken into account.
  - Do not cover the 1st generation cracks efficiently, especially in case that
    - Colloar plate is not fitted.
    - Slot direction is in the weaker way.

## Review of Slot Rules in CSR-O/T

Slot Strength Requirement in CSR-O/T (2/3)

- APPENDIX C Fatigue Strength Assessment
  - Fatigue strength of longitudinals is comprehensively evaluated, considered effective to prevent the 2nd generation cracks.
  - As an effective rule description to cater for the 3rd generation cracks, CSR only stipulates its recommended contour shape of slot cut-out confined to the case of arrangement without web stiffener connection.

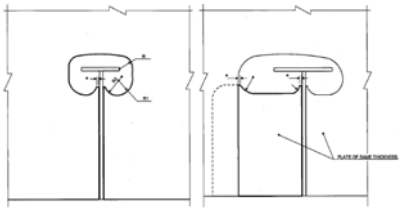


Figure: from IACS: CSR-O/T (2008)



## Review of Slot Rules in CSR-O/T

Slot Strength Requirement in CSR-O/T (3/3)

- APPENDIX C Fatigue Strength Assessment
  - However, some further points to be considered:
    - Even if fitted with web stiffener, it does not alleviate stresses exerted by shear force of primary member.
    - Softly shaped collar plate is not so effective against the load from longitudinals.
    - The Rule accounts for only the bending stress of longitudinals, but what is actually effective is the reaction force at the connection and the primary member shear force.
    - Low cycle fatigue from loading-unloading cycles is important in case of shuttle service.
  - Rather than employing prescriptive rule requirements, a more goal based approach with sufficient considerations onto the structural behavior is necessary, which has been actually practiced in some advanced shipyards as being part of their design standards.

## Slot Cut-out Strength through Three Generations

- Prescriptive Rules by nature account for limited representative or typical conditions and loads, and we cannot expect prescriptive Rules to be fully comprehensive, to cover daily improvement and new ideas on design. The goal is to design robust and efficient structure. To achieve this goal, the designers should devote all their energies to fully understand the actual structural behavior under various loads that will practically happen.
- "I am deeply impressed by the happy dispensation of Nature. And, it brings beneficence to those who have insight into it."

  by Dr. Mano
- If only simple and prescriptive Rules govern, such happy dispensation will not work any more.



## Extensive Structural Analysis Using Stress Response Function Method

### IHI-SPB Technology

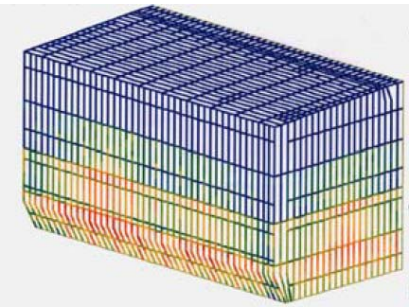
87,500 $m^3$ SPB LNG Carrier

POLAR EAGLE


Loading of SPB tanks

## SPB-HULL System

### Output of Automatic Fatigue Strength Calculation



**Slogan:**

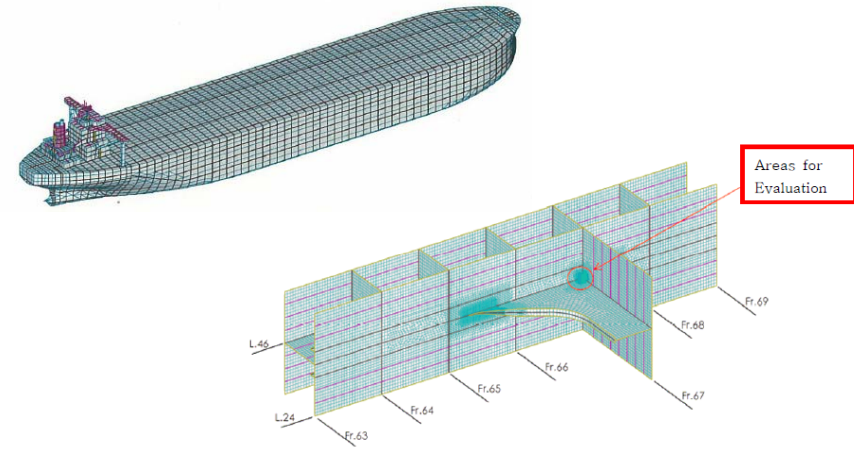
**Comb all over the structure exhaustively, and do not permit any water leakage of even one drop from the net of our assessment !**



## EXTENSIVE STRUCTURAL ANALYSIS
### Comparison btw ordinary & extensive analysis

| Ordinary Method | Extensive Analysis "SPB-HULL" |
|---|---|
| Equivalent Regular Wave Method | Stress Response Function Method |
| **Several Wave Case** | **All Sea Condition** |
| • Several dominant wave cases are selected for analysis.<br>– Pitching Max.<br>– Rolling Max.<br>– Bending Moment Max.<br>– Torque Max.<br>– ... | • Every Combination of<br>– Wavelength<br>– Direction<br>– Phase<br>• 4608 Cases for Structural Analysis |
| **Useful for Some Members** | **All Members** |
| • Max. stress is evaluated by selected dominant wave cases for specified structural member.<br>• Limit cases are useful at initial design stage. | • Stress Response Function is evaluated along all over the finite elements.<br>• Long-term prediction for every structure. |

## EXTENSIVE STRUCTURAL ANALYSIS
### Finite Element Models

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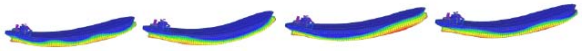
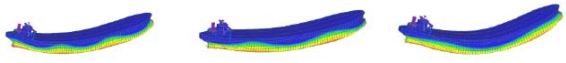
## EXTENSIVE STRUCTURAL ANALYSIS
### All sea conditions

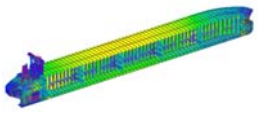
**Wave direction 24 Cases**



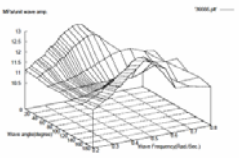
**Wave period (wave length) 32 Cases**



**Wave position (phase) 6 Cases**



**24 X 32 X 6 =**
**4,608 Load Cases**



Stress Response Function

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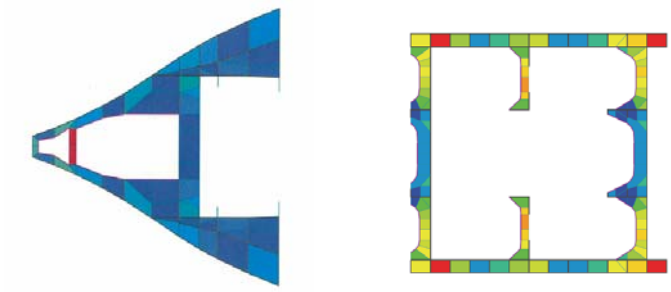
## EXTENSIVE STRUCTURAL ANALYSIS
### Strength Evaluation



4th Deck in Engine Room

Horizontal Stringer in Hold Part



## EXTENSIVE STRUCTURAL ANALYSIS
### Summary

**Structural Design: Successive improvement and introduction of new ideas**
**→ Structural behavior sometimes transcends past experiences.**
**→ Advantage to comb through all over the structure in all conditions**

**EXTENSIVE STRUCTURAL ANALYSIS**
**"SPB-HULL"**

- **All wave direction, wave period and phase**
- **Evaluate all the hull structure exhaustively**
- **Achieved highly reliable structure, preventing unexpected failure proactively**

## Conclusions (1/2)

1. CSR introduced increased hull scantlings, and thus safety level has been upgraded.
2. Due to its prescriptive nature, considerations of some aspects of very detailed structural behavior are left to designers. By considering and understanding such structural behavior, equivalent or more robust structural design can be achieved with less hull steel.
3. As examples of such structural details, longitudinally successive girders / stiffeners with different depths and slot cut-out arrangement were discussed. Some examples showing how to prevent damages not efficiently covered by CSR were shown.
4. In addition to such approach depending on designers' insight and ability, progress in computational technology allows us to carry out exhaustive finite element analysis, combing all the hull structural elements under all the wave directions, wave period and phase. "SPB-HULL" system is applied to all the new designs in IHI Marine United Inc., and is contributing to the enhanced safety of our ships.



## Conclusions (2/2)

5. The goal is to achieve robust and efficient hull structure. Prescriptive Rules only help achieving this goal in an already experienced and well-established structural arrangement. To achieve the goal in more efficient way and in the field of novel engineering,
   - the designers' insight and profound understanding into the structural behavior, and
   - the "SPB-HULL" exhaustive finite element analysis

   are a pair of wheels, both working closely together.

**THANK YOU**

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