SUB-COMMITTEE ON FIRE PROTECTION
55th session
Agenda item 19

FP 55/INF.3
23 May 2011
ENGLISH ONLY

DEVELOPMENT OF GUIDELINES FOR USE OF FIBRE REINFORCED PLASTIC WITHIN SHIP STRUCTURES

Information and experimental data from testing and approval of fibre reinforced plastics for ships

Submitted by Sweden

SUMMARY

Executive summary:	This document provides background information and experimental data from testing and approval of FRP structures, related to the proposals in document FP 55/19/1
Strategic direction:	5.2
High-level action:	5.2.1
Planned output:	5.2.1.32
Action to be taken:	Paragraph 7
Related documents:	FP 55/19/1; MSC/Circ.732; resolution MSC.45(65); MSC/Circ.1002; MSC 87/24/9; MSC 87/26 (paragraphs 24.14, 24.31 and 24.39.3); C 104/D (paragraph 8.2 (iii)); and SOLAS regulation II-2/17

Introduction

1 The Maritime Safety Committee, at its eighty-seventh session, agreed to include, in the biennial agenda of the FP Sub-Committee and the provisional agenda for FP 55, an unplanned output on "Development of guidelines for use of fibre reinforced plastic (FRP) within ship structures", with a target completion year of 2013 (paragraphs 24.14, 24.31 and 24.39.3 of document MSC 87/26). The decision was endorsed by the Council at its 104th session (paragraph 8.2 (iii) of document C 104/D).

2 The new output was initiated by document MSC 87/24/9 (United Kingdom). In this document, reference is made to a fire test procedure specific to FRP construction of combustible nature with a starting point in MSC/Circ.732 and resolution MSC.45(65).

3 Based on experiences from 15 years of fire testing of more than 50 full-scale test of FRP structures in accordance with the procedure outlined in resolution MSC.45(65), Sweden submits proposals for the way ahead in document FP 55/19/1. In this document, additional information and points for consideration when establishing guidelines for fire testing of FRP structures is given. The tested full-scale specimens have been of various materials,

including PVC core, balsa core, PMI core, SAN-foam core, glass and carbon fibre laminates, and various resin systems including polyester, vinyl ester and phenolic. Tests have also been carried out on composite structures with penetrations of pipes, ducts and cables, and on the integration of fire rated windows and fire doors. General comments apply to all types of load-bearing and non load-bearing divisions of FRP.

Background

4 Experimental data from fire tests of FRP decks and bulkheads according to resolution MSC.45(65)

Twenty-nine tests of decks and bulkheads performed by SP Technical Research Institute of Sweden and other laboratories have been studied in detail. The tests performed by SP were tests of laminate/PVC-foam core/laminate FRP constructions insulated on the fire exposed side. The decks consisted of panels with stiffeners on the underside and the bulkheads consisted of unstiffened panels. The resins were of polyester or vinyl ester and in one case phenolic.

Tests performed by other laboratories include tests of balsa, PMI and SAN-foam cored sandwich constructions. The decks consisted of panels with stiffeners on the underside and the bulkheads consisted of panels with stiffeners on the exposed side. The resins were of polyester and vinyl ester, some manufactured by hand layup, others by resin infusion. All panels were made in a FRP shipyard environment.

4.1 Bulkheads

The temperature at the interface laminate/insulation was measured during the tests. The number of measuring points was 2-5/bulkhead panel and 1/stiffener in the bulkheads with two stiffeners. There was a spread in the temperatures measured in the bulkhead respectively. The minimum and maximum temperatures at or close to an anticipated loss of structural integrity varied between 249-580 and 196-560°C respectively at the panels, and the temperatures at the stiffeners were 595 and 580°C, respectively. The minimum and maximum temperatures measured at the termination of the test respectively and the HDT-temperatures, when known, are shown in figure 5 at the annex.

There was no clear expansion or contraction of the bulkheads until a final phase when contraction could be noticed close to the loss of structural integrity. The final phases leading to collapses could be perceived 0,7-4 minutes before the collapse of the bulkhead, respectively.

The horizontal deflection of the bulkheads was measured during the tests. Typical time-deflection patterns are shown in Figure 1 at the annex. Approximately 10 minutes or more before the loss of structural integrity most of the bulkheads indicated, by changing the direction of the horizontal deflection a change of the stiffness of the bulkheads. The minimum and maximum temperatures measured at the interface laminate/insulation of the bulkhead panels when the horizontal deflection direction of the center of the bulkhead respectively changed varied between 140-215 and 89-165°C, respectively, and the temperature at the stiffeners was 45°C.

The horizontal motion of the vertical edges followed mainly the pattern of the centre of the bulkhead, but the amount of deflection was much less than the deflection of the centre of the bulkheads, see Figure 1 at the annex. Together with visual observations of the location of damages of the exposed side of the structural core after the tests this indicates that the temperature close to the vertical edges is lower than at the central part.

4.2 Decks

The temperature at the interface laminate/insulation was measured during the tests. The number of measuring points was 2-5/deck panel and 2-4/pair of stiffeners. There was a spread in the temperatures measured in the deck, respectively. The minimum and maximum temperatures at or close to an anticipated loss of structural integrity varied between 179-480 and 137-400°C, respectively at the panels and between 299-515 and 235-430°C, respectively, at the stiffeners. The minimum and maximum temperatures measured at the termination of the test respectively and the HDT-temperatures, when known, are shown in Figure 6 at the annex.

All decks indicated, by the time-deflection pattern, that the stiffness of the decks decreased, starting 5-10 minutes after the start of the heating, and that the loss of stiffness was accelerating throughout the tests. Typical time-deflection patterns are shown in Figure 2 at the annex.

During one test the panel and the stiffeners separated, without loss of the structural integrity. During another test parts of the core of the stiffeners softened, became "fluffy" and lost all stability resulting in a decrease of the height of the stiffener.

4.3 Critical temperature levels

In literature, indications on some critical temperatures levels for materials of FRP constructions were found. Bearing those levels in mind, the temperatures measured at the interface laminate/insulation at the losses of structural integrity were found to be surprisingly high.

Degradation of resin

- when the glass transition temperature or heat distortion temperature is reached, the resin softens and the strength of the laminate decreases. Polyester and vinyl ester resins have a glass transition temperature from 70-120°C, epoxy resins from 65 to approximately 150°C and phenolic resins can have over 150°C. The glass transition temperature is strongly dependent on post cure – if elevated temperature is used, the glass transition temperature increases. The tensile modulus and strength of the laminate is reduced less than the compressive properties due to the loss of support for fibers in the compression mode. This could explain the difference in behaviour between decks and bulkheads. There is tension in the laminate in the lower parts of deck stiffeners and there is compression in the exposed side laminate of bulkheads;

- mass loss for polyester and vinyl ester resins starts to occur at about 200°C.

Degradation of the core

- the core will lose stiffness at its softening temperature, for PVC around 90-120°C, for PMI around 180-200°C. Balsa does not have a softening temperature, but starts to char lightly at around 220°C.

Degradation of the interface laminate/core

- the bond strength of the laminate/core interface is a function of the softening of the resin and the core.

Degradation of fibres

- degradation of the fibre reinforcement is initiated at approximately 400°C for E-glass, higher for carbon fibres.

Discussion

5 Discussion on MSC/Circ.732 and full scale tests of load-bearing divisions

According to MSC/Circ.732, non-combustible FRP-divisions should be tested in small scale with load and without insulation to find the relationships between applied loads and temperature. The small-scale test should be followed by a full-scale test without load and with a critical temperature, at any point, as criteria. The critical temperature is the temperature of the composite strength corresponding to the most critical applied load relative to the application on board and should not exceed the transition temperature, when applicable.

MSC/Circ.732 defines transition temperature (which should not be exceeded) as the temperature corresponding to an abrupt loss of stiffness of the material. From the tests described in paragraph 2, no abrupt loss of the structural integrity on a global basis was found. The loss of structural integrity was always preceded by a deflection downwards with accelerated speed for decks and by a horizontal deflection with accelerated speed and often including one or two changes of the motion direction for bulkheads.

The tests described in paragraph 4 indicate that there is no single global transition temperature for a construction, the route to collapse is gradual and accelerating, and the loss of structural integrity occurs at a temperature distribution on a "global" structural level. The loss of the structural integrity was a function of complex constructions, the global temperature distribution and the resulting strength at different parts of the constructions. Components, factors and variations having an impact on the structural integrity were:

- the anticipated transition temperature within stiffened structural cores varied within the construction
  - o different parts of the structural core were constructed of different materials – different laminates, resin and/or fibre composition, and different core materials in panel and stiffener, respectively;
  - o stiffeners were constructed with different laminate, resin and/or fibre composition, on the webs and the flange, respectively;
  - o attachment laminate panel/stiffener;
- insulation was different at the panel and stiffener, respectively, from the stiffened constructions;
- the temperature at the interface laminate/insulation measured at different locations of components with uniform insulation varied, see paragraphs 4.1 and 4.2.
  - o a major number of the variations in temperature was probably depending on, e.g., mounting of the insulation, variations in the insulation material and impact of the structural deflection;

  - o there were anticipated "cold" and "hot" areas within components with uniform insulation, e.g., at insulation pins, joints in the insulation system, inner corners and outer corners. See also figure 3 at the annex;

  - o insulation joints that open up during the test may imply an increase in temperature. One of the deck test was assessed to fail due to opening up of insulation joints;

- the constructions worked as units. All parts of a construction co-operate to the structural integrity. When local loss of strength appears stresses will be redistributed and other parts of the construction will be more utilized.

The tests of FRP divisions described in paragraph 4 indicate that full scale tests according to Part 11 of resolution MSC.307(88) could be considered to be more appropriate than the present guidelines in MSC/Circ.732, that is made for non-combustible composites. Divisions tested loaded in full scale can be arranged to include critical components parts of different constructions and materials and parts with different insulation. A full-scale test with load will include the effect of load-imposed deflections and any effect this has on insulation systems and do also include the possibility for redistribution of stresses in the construction.

Guidelines

6 Guidelines for testing of FRP structures

Based on the experiences gained during the previously mentioned 15 years of testing, Sweden believes that it is essential to present some reflections and thoughts in relation to the development of guidelines for testing of FRP structures.

Principles for testing load-bearing constructions outlined in test methods ISO 834-1, 4, 5, 6 and 7 should be considered and appropriate parts should be utilized in the guidelines. When developing the guidelines the following points should also be taken into account.

6.1 General

The guidelines should describe rules similar to the rules in resolution MSC.307(88) Part 3, Appendix 1, Paragraph 1 General, e.g.:

- there is a need to define a test on the minimum FRP scantlings anticipated to be used, i.e. minimum amount of reinforcement in laminates, minimum thickness and density of cores, minimum height and scantlings of stiffeners (if applied), etc. This minimum scantlings shall be tested with a corresponding load;

- the exposure direction for decks should be addressed. Would a real fire from above, due to the nature of FRP structures, cause loss of structural integrity? Can this be treated the same way as for, e.g., aluminium decks on HSCs where no insulation is required in the presence of a fixed active sprinkler system?

- general and restricted application for bulkheads;

- can materials not included in the test be mounted on top of decks on board? As FRP structures are inherently insulating, there is little effect on temperature on the critical side by adding insulation or other materials on the unexposed side;

- changing of materials – fibres (type, amount and direction), resin (type and amount) and core material.

6.2 Design and description of the test specimen

All critical components and details regarding temperature and strength, e.g., joints in the insulation system and joints between members of the structural core including joints between panels, insulation pins and other anticipated critical or "hot" spots should be included in the test specimen.

A guide on relevant constructional details to be described in the test report should be developed. Minor changes in recipes might change the material properties when heated, grooves and perforation of the core, joints in the structural core, fixing of insulation and location of insulation joints may all be relevant details.

6.2.1 Size of the test specimen

If, in practice, the height or width of a bulkhead is 3m or smaller, then that dimension of the test specimen should be tested in full size. If any dimension of the construction is greater than 3m, then that dimension should be tested at not less than 3m (3m width instead of 2.44 m – due to temperature boundary effects close to the vertical edges which has an impact on the structural integrity, 3m height instead of 2.5m – the height has an impact on the structural integrity).

The minimum dimensions of a deck should make it possible to host critical components and "hot" spots where the deck is exerted for the maximum bending moment and shear force. The minimum dimensions described in ISO 834-5 should be considered.

6.3 Connection of composite constructions to metallic structures

The guidelines should address connections between FRP structures and metallic structures.

6.4 Loading

6.4.1 Selection of load

There is no indication from the tests described in paragraph 5 that the load prescribed in part 11 of resolution MSC.307(88) is representative for all loads and dimensions of the test specimens. The load shall be based on the anticipated load in the final ship structure.

6.4.2 Primary and secondary span of decks

Decks constructed by a panel with stiffeners on the underside are spanning two ways, a primary span along the stiffeners and a secondary span transverse the stiffeners. In practice it is complicated to simulate a uniformly distributed load representative for both spanning directions during one test. This should be addressed in the guidelines.

6.4.3 Critical elements and details

A deck should be loaded so that each critical element or detail regarding temperature and strength of the construction is represented in parts where the maximum bending moment and maximum shear force appears. See examples of loading strategies and the resulting distribution of the maximum bending moment and shear force in Figure 4 at the annex.

6.5 Cooling curve

After the termination of heating, the temperature of the exposed side of the structural core is likely to keep on rising for some time. In case it is of interest to know if the construction will maintain the structural integrity after the fire has been extinguished, the heating period could be followed by a cooling phase with the construction still loaded. This would indicate whether the construction will collapse after the fire or not. Examples of cooling curves should be indicated in the guidelines.

6.6 Clarification of Part 11 of resolution MSC.307(88)

For bulkheads the performance criteria for load bearing ability is a limiting axial contraction and limiting rate of axial contraction. For decks the criteria for load bearing ability is a limiting deflection and limiting rate of deflection. It is not clear if the contraction and deflection respectively should be measured from the time of application of load or from commencement of the heating period. This should be clarified in the guidelines.

6.7 Openings in bulkheads and decks

The guidelines should indicate if doors, windows, pipe penetrations, cable transits, fire dampers, etc., should be tested in bulkheads and decks with or without load. In general, if the structural performance during fire of the actual FRP structure is documented by a loaded fire test, these type of penetrations can be tested without load applied in the test, as the structural analysis will determine if local reinforcement is needed in way of cut-outs.

Action requested of the Sub-Committee

7 The Sub-Committee is invited to note the information provided.

***

ANNEX

FIGURES AND GRAPHS ILLUSTRATING INFORMATION AND EXPERIMENTAL DATA

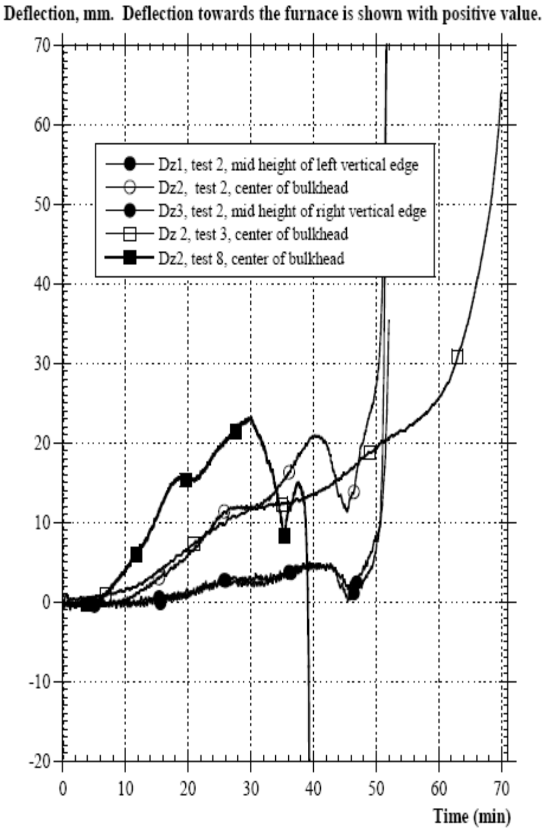


Figure 1: Horizontal deflection of four bulkheads

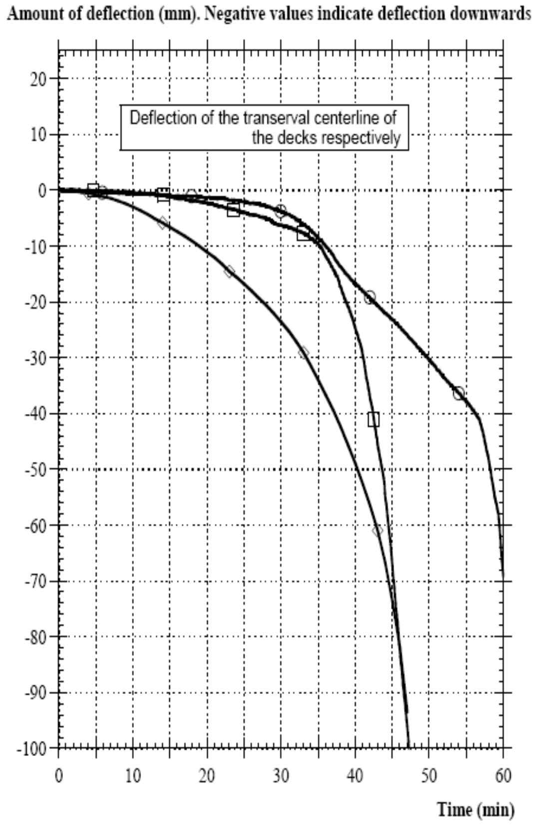


Figure 2: Amount of vertical deflection of three decks

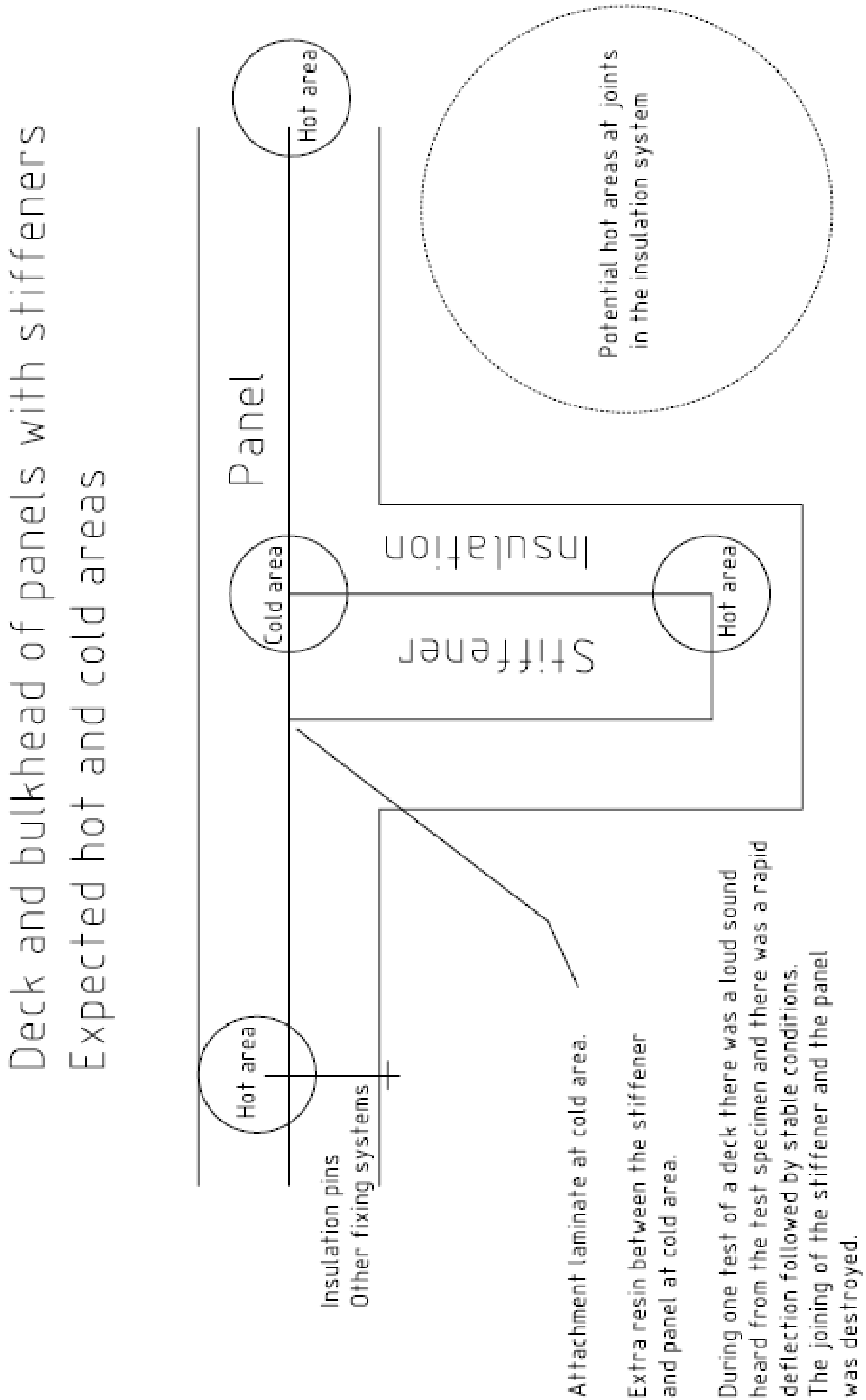


Figure 3: "Cold" and "hot" areas within the specimen

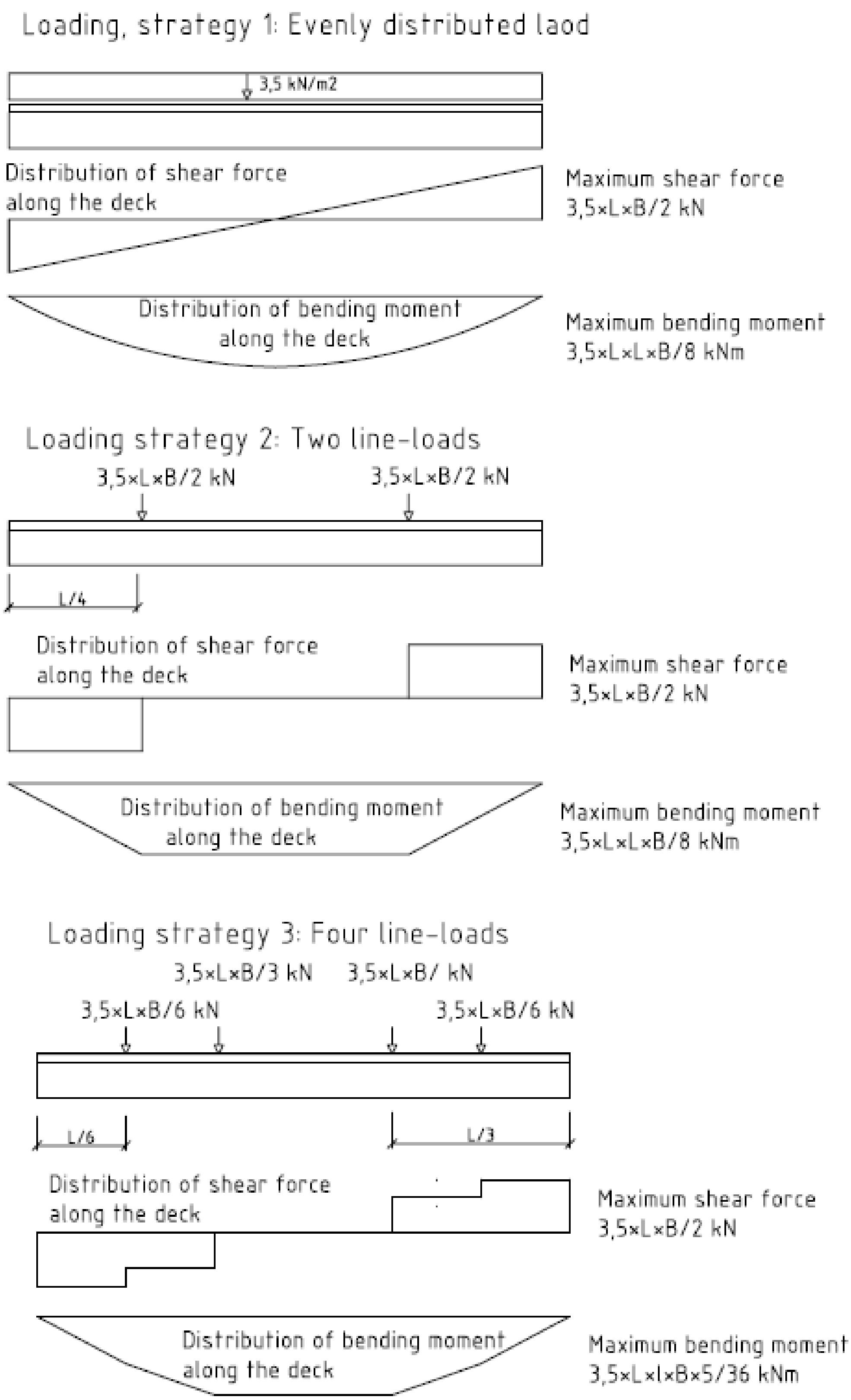


Figure 4: Examples of distribution av bending moment and shear force as a function of loading strategy

Figure 5
Bulkheads: Maximum and minimum temperatures at inteface exposed side laminate/insulation

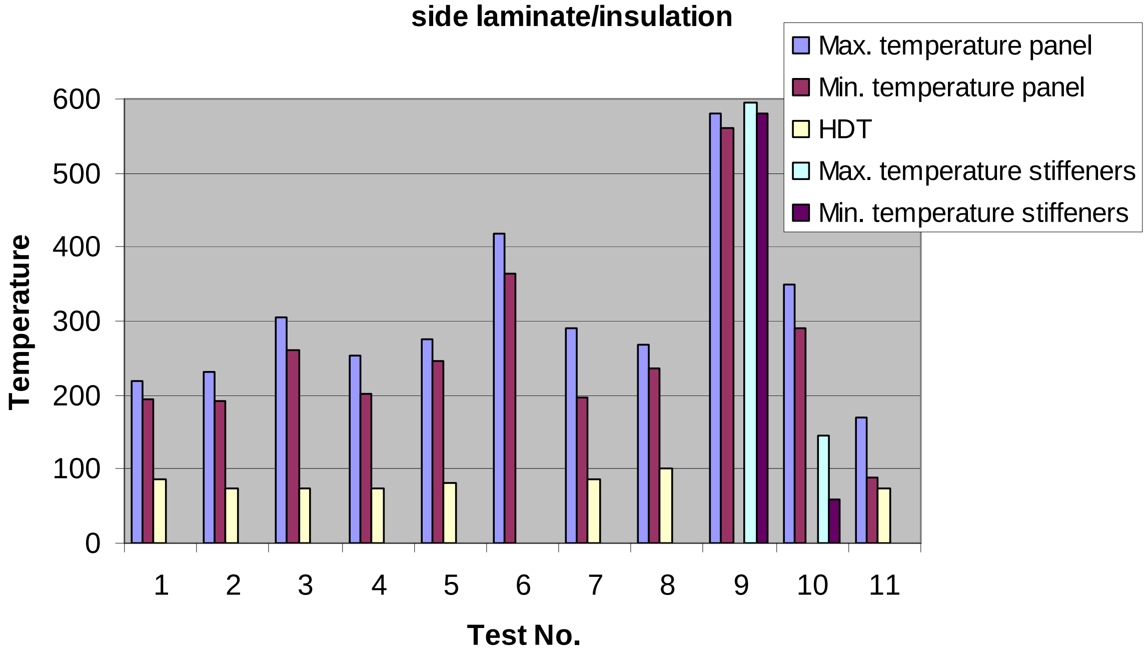
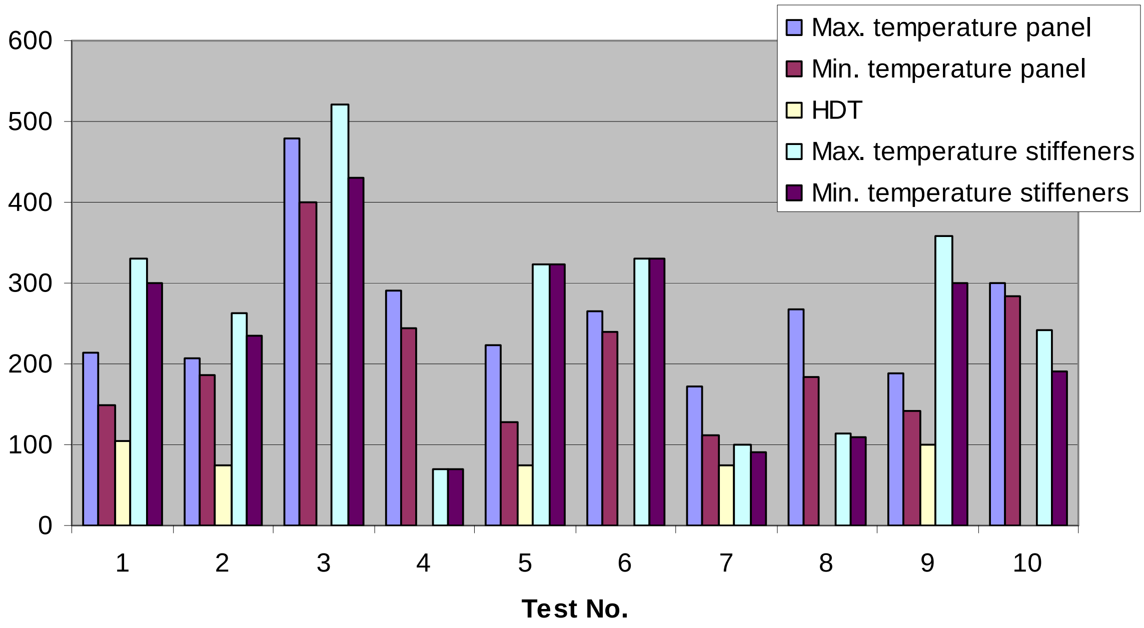


Figure 6
Decks: Maximum and minimum temperatures at interface laminate/insulation



___