Unique thin walled shells with large span used as roofstructures

Autor(en): **Hammarström, Lars / Samuelson, Lars Å.**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **13 (1988)**

PDF erstellt am: **21.06.2024**

Persistenter Link: https://doi.org/10.5169/seals-13091

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

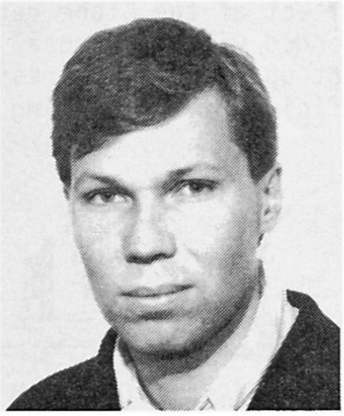
http://www.e-periodica.ch

Unique Thin Walled Shells with Large Span Used as Roofstructures

Dünnwändige grosspannige Schalen verwendet als Dachstrukturen

Coques de mince épaisseur à grande portée employées comme structure de toit

Lars HAMMARSTRÖM
Götaverken Arendal AB
Gothenburg, Sweden



Lars Hammarström received his Masters degree in Civil Engineering from Chalmers University of Technology, Gothenburg 1986. He has been working with marine structures at GVA since then. Mainly offshore structures as for example Tension Leg Platforms and the new Swedish Icebreaker.

Lars Å. SAMUELSON
Swedish Plant Inspectorate
Stockholm, Sweden

Lars Å Samuelson received his Masters degree from the University of Technology, KTH, in Stockholm 1961 and his Ph D in Engineering in 1969. Worked 1961–1979 for the Aeronautical Res Inst of Sweden. He is presently responsible for research and development in stability of shells at the Swedisch Plant Inspectorate. Member of ECCS TWG 8.4.

SUMMARY

A unique design of the spherical roof of the Stockholm Globe Arena was proposed by the Engineer based on years of experience in shipbuilding. Vertically stiffened thin-walled plates welded to form spherical segments were to be assembled on site and hoisted in place on the supporting ring of the base structure. The design work primarily concentrated on the stability of the shell structure, utilizing linear bifurcation, non-linear collapse and non-linear dynamic analyses for a number of static and dynamic load case, including accidental loads.

ZUSAMMENFASSUNG

Die in seiner Art einzige Konstruktion von dem sphärischen Dach für die Stockholm Globe Arena gründet auf langjährigen Erfahrungen im Schiffbau. Vertikal versteifte dünnwändige Stahlbleche, on site zusammengeschweisst zu sphärischen Segmenten, sollten auf ihren Platz auf den tragenden Ring von der Grundstruktur gehoben werden. Die Konstruktionsarbeit wurde primär auf die Stabilität der Schalenstruktur eingerichtet.

RÉSUMÉ

Un projet unique du toit sphérique de la Stockholm Globe Arena basé sur plusieurs années d'expérience dans l'architecture navale a été proposé. Des lames de mince épaisseur, avec raidissement transversal, soudées pour former des segments sphériques, devaient être assemblées sur place et finalement levées pour montage sur le cercle de support de la structure de base. Le projet traite essentiellement de la stabilité de la structure de la coque.

1. BACKGROUND

In the development of light-weight structures, the tendency has been towards use of unstiffened and stiffened shells. Examples are aircraft and automobile structures. Steel ships were always built as shell structures and, when GVA moved into the offshore branch of floating constructions it was natural to utilize true shells rather than the current compromise between beam and plate structures. This was appreciated by the market.

When approached by the architect of the Globe regarding the possibility to build the spherical roof GVA responded with a proposal for a stiffened shell structure. The design was not optimized with respect to weight but with respect to the total cost trough efficient manufacturing and erection procedures.

Fig. 1.1 Conception of the STOCKHOLM GLOBE ARENA

In the final competition the building contract was awarded to MERO and the GLOBE was finally built as a shell-like 3-D truss covered by prefabricated panels.

2. BASIC GVA DESIGN

The GLOBE is a half sphere of 110 m diameter supported by a heavy ring at the equator 35 m above ground level. Fig 2.1 The ring is supported by 48 arched columns forming the lower part of the building. The GVA design included a heavy ring at the 80 m level forming the support for the suspended equipment weighing approximately 200 tons.

The shell structure proposed was built up from 144 singly curved sheets to which the vertical T stiffeners were welded. The stiffened sheets were to be manufactures at the GVA plant and shipped to Stockholm. On site three by four sheet were to be joined together into segments by a special zig-zag welding technique developed by GVA in order to minimize distorsions.

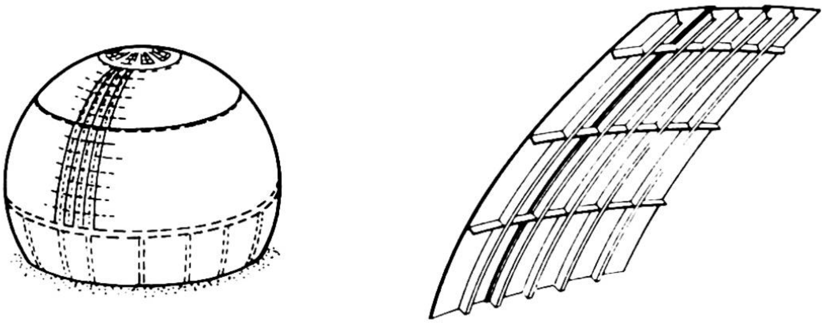


Fig. 2.1 Overview and detail of proposed structure

Erection of the structure was planned according to Fig. 2.2. First the central cap and the upper ring would be assembled on the ground and lifted to the final position by four large cranes. Subsequently, the shell segments were to be hoisted into place and welded.

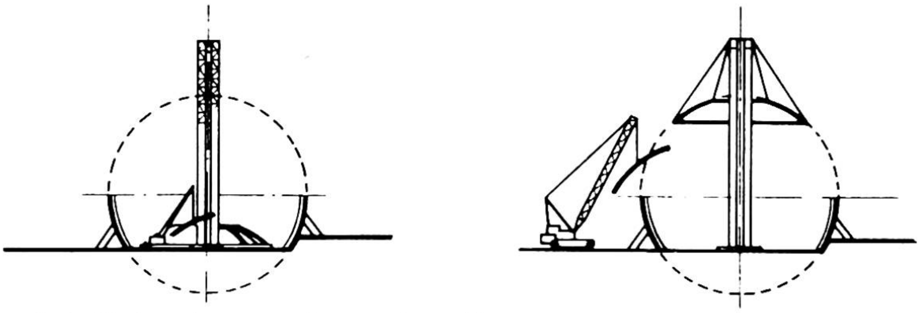


Fig 2.2 Main phases of construction

3. DESIGN PHILOSOPHY

The manufacturing technique for the proposed dome structure is based on well established ship building practice. Since the structure may be characterized as a thinwalled shell, the design analysis differs from that of the shipbuilding technology where, mostly, plane panels are used. Shell analysis requires consideration of imperfection sensitivity and the effect of local forces and nonuniform pressure distributions. A safe design may be based on the following criteria:

The basic structure treated as a ring stiffened orthotropic shell of revolution may be analyzed by use of special purpose computer programs. Initial estimates of the elastic buckling loads are obtained for an equivalent axisymmetric pressure distribution and, the carrying capacity is estimated by application of realistic reduction factors . Such factors may be approximately extrapolated from codes and experimental results presented in the literature. Final verification of the design is achieved through extensive non-linear analyses of the collapse behavior for a number of static and dynamic forces including catastrophic load cases. The design requirements are summarized in Fig 3.1.

The stability limit may be determined by use of bifurcation or collapse analysis or a combination of the two methods. Since the globe structure may be characterized as a shell of revolution, buckling analysis by use of linear bifurcation is easily carried out by use of special purpose programs. However, the calculated buckling load may be a very poor estimate of the carrying capacity and an appropriate reduction factor must be applied. According to Det norske Veritas (DnV) a reduction factor of 0.05 would apply for the unstiffened sphere, where as a value of 0.1 to 0.2 may be realistic for the stiffened shell being proposed.

In a non-linear collapse analysis considering the nonsymmetric load distributions, initial deflections and other disturbances a reduction factor should not be necessary. However, it is strongly recommended to apply a factor of safety exceeding the value of 2.

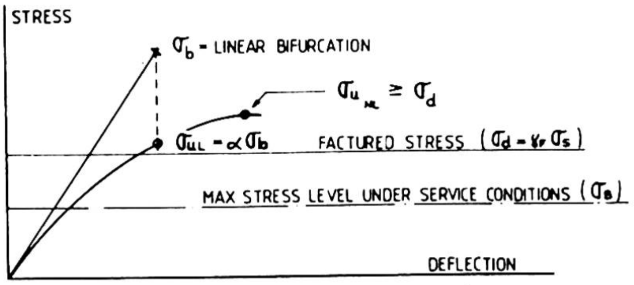


Fig 3.1 Definition of safety requirements

4. LOADS AND DISTURBANCES

The Swedish building code requires design with respect to a number of acting forces including wind and snow loads. The actual load distributions for the Globe were interpreted as shown in Fig 4.1, where the wind pressure distribution was taken from the Swiss code, 1 . In addition, two accidental load cases were considered. The first one simulates the loss of one of the support columns and the second an impact of a small airplane (see Fig 4.2). The load cases are numbered as follows:

Table 1. Definition of load cases

Load case no	acting loads
1	Eigenweight
2	Eigenweight + snow load
3	Eigenweight + wind pressure
4	LC 2 removal of support leg
5	LC 2 impact of small airplane: Shell section 5x5 m removed when max stresses reached in impact area

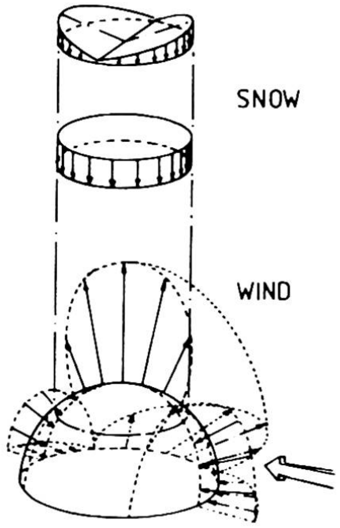


Fig 4.1
Environmental loads

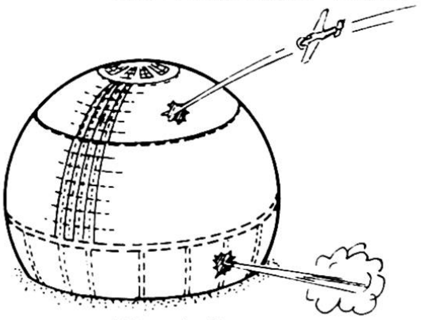


Fig 4.2
Accidental loads

5. MODELS AND METHODS OF ANALYSIS

Two basic models where used in the analysis. Since the Globe may be characterized as an orthotropic shell of revolution, certain stability problems may be readily treated by use of special purpose programs such as BOSOR4, 2 . The model, as shown in Fig. 6.1 includes discrete rings (horisontal) and 288 vertical stiffenes treated as smeared. This model was used for preliminary design of the stiffening system.

BOSOR4 does not have the capability to analyze buckling under nonsymmetric loads. Such cases were modeled in SOLVIA, (ADINA) 3 . Fig 6.2 shows the two FE models used in the analyses performed, including dynamic response. By necessity the shell and beam elements were lumped in order to reduce the size of the problem to a reasonable level.

BOSOR4 was used to analyze axisymmetric load cases including an approximation of the wind pressure distribution in the manner deviced in the German DASt rules, 4 . The program gives the stresses in the shell and the bifurcation buckling loads and it is a powerful tool in the early design phase. The program has a branch for computation of the eigenmodes and eigenfrequencies of the structure.

The sphere is very sensitive to imperfections and nonsymmetric loads, and it was essential to evaluate the influence of these parameters by use of nonlinear, large displacement theory. SOLVIA was used for this purpose and, for instance, discrete support loads, weights attached to the upper ring etc could be easily modeled. In addition linear eigenvalue problems can be handled by SOLVIA.

6. RESULTS

The BOSOR4 analysis showed that load case no 2 is the most critical since the wind produces suction at the crown. Typical results are shown in Fig. 6.1, indicating that buckling occurs above the ring in the area where two way compression exists. BOSOR4 was used in the preliminary design and Table 2 includes results for the unstiffened and vertically stiffened only designs. Dynamic analysis indicated a minimum eigenfrequency of 7 Hz.

Table 2 Linear bifurcation buckling analyse

		Load factor	Waves	
Unstiffened	LC 1	2.4	3	BOSOR4
432 Stiffener no rings	LC 1	6.3	90	BOSOR4
432 Stiffener no rings	LC 3	85.0	30	BOSOR4
288 Stiffener 10 rings	LC 2	38.0	25	BOSOR4
288 Stiffener 10 rings	LC 2	13.0	2	SOLVIA

Table 3 Non-linear large displacement analyse SOLVIA

	Load factor	Displacement nod D mm	Max eff. stress MPa
LOADCASE 2	1.0	20.0	35.5
LOADCASE 2	3.0	64.0	107.2
LOADCASE 3	1.0		
LOADCASE 3	3.0		

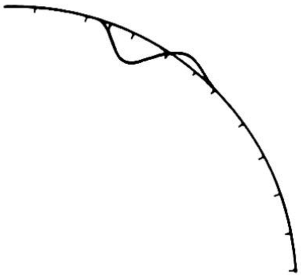


Fig 6.1 BOSOR Model and LC 2 critical buckling mode

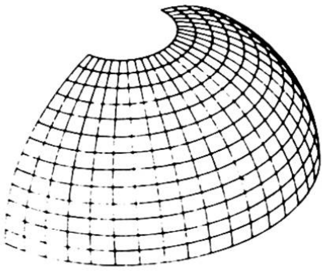


Fig 6.2 FE Model

The SOLVIA/ADINA program was utilized for linear bifurcation analysis of load case no 2, Fig 6.5 where the effect of the suspended point load could be included. The load factor of 13 is probably a slight underestimation since the cap was not included in the model.

Non-linear analyses were carried out for load cases 2 and 3. Sample results are shown in Figs 6.3 and 6.4. It was found that deflections and stresses are small and that their dependance on the load is practically linear up to a factor of three times the base load. The results are summarized in Table 2.

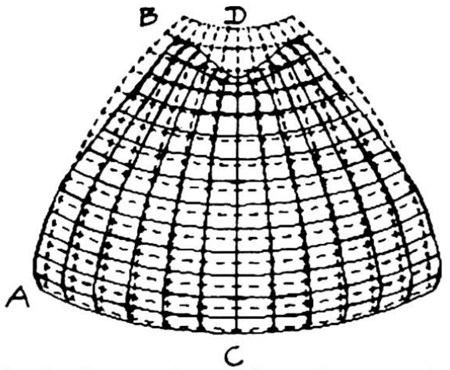
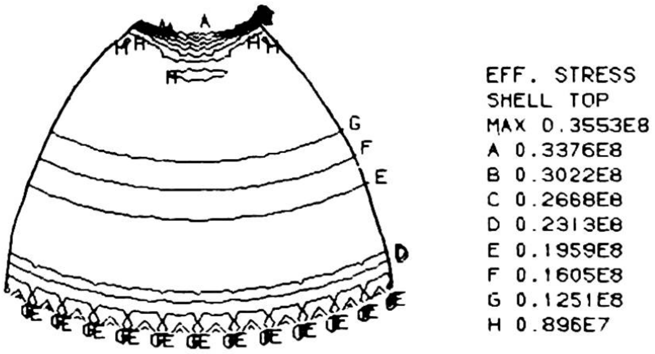


Fig 6.3 Deformation plot for LC 2



Stress plot for LC 2

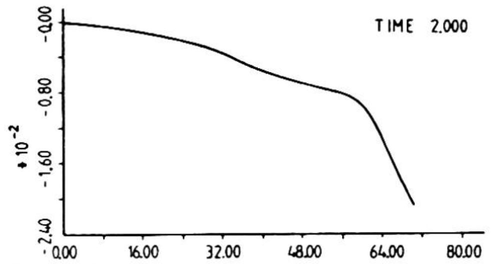
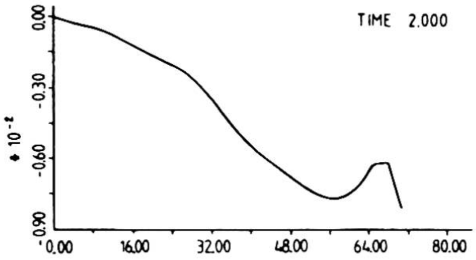


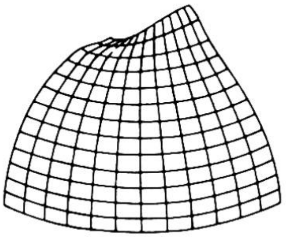
Fig 6.4 Displacement along line AB see Fig 6.3



Displacement along line CD

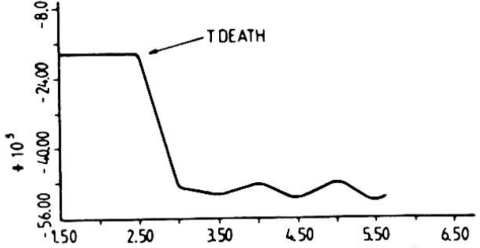
Finally a number of dynamic analyses were run simulating load cases 4 and 5. Case No 4 proved not to be critical. In case 5 the analysis was run in two steps. First the deflections of the intact shell due to the impact were calculated. At the time of maximum stress the impactor was assumed to rip a hole in the shell and the analysis was carried out for a few cycles. The shell was pre-loaded as in case No 2. Sample results are shown in Fig 6.6.

Fig 6.5



Buckling modes LC 2

Fig 6.6



Axial stress respons at edge of hole, LC 5

7. DISCUSSION

The proposed stiffened shell design of the GLOBE was shown to fulfill all requirements of the Swedish Building Code and additional accident/sabotage related load cases. Because of the extreme dimensions of the structure - the r/t ratio of the shell plating equals 7000 - extra safety margins were considered. As a matter of fact, optimization of the structure would lead to some weight reduction but, handling and assembly would require more sophisticated procedures. The total cost of the proposed GLOBE design may thus be assumed to be reasonably close to the optimum.

REFERENCES

1. SIA 160, Swiss Building Code
2. BOSOR4, Users Manual, 1986
3. SOLVIA-IN, Users Manual, 1987
4. DEUTCHE AUSSCHUSS für STAHLBAU Ri 013
5. SBN 80, Swedish Building Code, 1982:3