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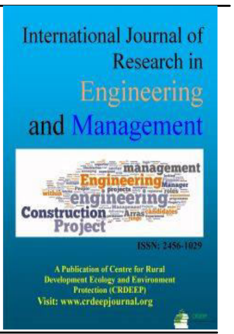

Full Length Research Paper

Stability of Shell Roof Structures under Different Load Types

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ABSTRACT

Shells roof structures are important components of many industrial complexes. Performance of shells due to the extreme loading conditions shows that buckling is the major failure mode in such components. Shells have several applications in engineering structures and most particularly in civil engineering, and mechanical engineering, architecture, aerospace and marine industries. This research aims to indicate the Stability of Shell Roof Structures under Different Load Types. Shells roof structures of different geometric specifications (including radius (R), base radius (r), height (H), and thickness), types of loading were considered. Result of this study revealed that geometric of shells can play a noticeable role in creating stress concentration and affect destructively the stability of structures. The contribution of this study is to present a reveal that the different load types on shell roof structures can play a noticeable role in creating stress concentration and affect destructively the stability of structures.

Introduction and backgrounds

Shells are important components of many industrial complexes. Performance of shells due to the extreme loading conditions shows that buckling is the major failure mode in such components. Shell structures are widely used in the fields of civil, mechanical, architectural, aeronautical, and marine engineering and have several applications in engineering structures and most particularly in these fields. Shell technology has been enhanced by the development of new materials and prefabrication schemes. Despite the mechanical advantages and aesthetic value offered by shell structures, many engineers and architects are relatively unacquainted with shell behavior and design. In the case of studying shell structures, three aspects must be taken into consideration: the Physical behavior, the structural analysis, and the design of shells in a simple, integrated, and yet concise fashion. In this regard, wide investigations have been conducted by the researches. Thus, this research aims to indicate the stability of shell roof structures under different load types. A new structural system, namely steel-concrete composite shells, for enclosing large spaces. These composite shells were formed by pouring concrete on a thin stiffened steel base shell which serves as both the permanent formwork and the tensile steel reinforcement. The new system retains all the benefits of. Thin concrete shells, but eliminates the need for temporary formwork. In addition, minimizes the required false work. A study to demonstrate the feasibility of constructing these. Shell roofs of large spans with very thin steel sheets and a limited amount of shoring was presented (Teng, Wong, Wang, & Dong, 2005).Computer techniques can be used to find alternative geometries of shell structures to improve their mechanical behavior.

This paper shows how the field of use of computers may be widened using these techniques in the design of concrete shells. Some optimum geometric designs of an actual concrete shell were found (Tomás & Martí , 2010). Straight and curved models of the steel shell roof with different plates were analyzed, designed and compared. Three types of shell roofs were considered: duo pitch, cylindrical and dome. Main objective was to compare the straight and curved model of the shells. Research shows how effective the curved surfaced shell roof can be with different angles in helping the structure to resistance it is self-weight and applied loads. This kind of shell roof is not common in all shapes and each model needs special characteristics. An optimal structure with the largest span of shell Roof and resistance to loads was obtained. It was showed under which conditions a particular structure can be more reliable.

The results were compared in order that a structure with ideal condition can be obtained in future. Research shows how effective the curved surfaced shell roof can be with different angles in helping the structure to resistance it is self-weight and applied loads. This kind of shell roof was not common in all shapes and each model needs special characteristics. The research showed that it was necessary and important to consider the maximum possible loads these structures could carry. This kind of design was very economical in shell structures and had the capability of replacement and frequent usage (Behnamasl, 2010). The design of a roof for a basketball arena, which had a capacity of 20,000 spectators. The size of the stadium was large enough to demand a long spanned shell structure. An elegant attempted to find solution to this problem, which combines aesthetic and structural beauty with efficiency during construction. A literature study was done in an attempt to create a plan for the design of the shell roof. The general theory of shells was studied to understand their forms, structural behavior and modes of failure. This helps the designer to understand the mechanics of shells, which heavily influence the design procedure. Existing basketball arenas were also examined to find out the loading requirements for the roof in this thesis.

The design was finalized by defining the structural framework, and proposing the paneling and connection details (Kanta, 2015). Only by understanding, concrete shells' loss in popularity can designers be equipped to create and apply this type of construction. It was presented a cultural perspective and an overview of seminal, historical and contemporary concrete shells. It asked the question to what constituted their popularity and factors that led to their demise in the modern age of technological advancement, construction process and environmental concerns (Tang, 2015). Mesh-reinforced sandwich shell roof to be built in Dübendorf, Switzerland, in 2016. Nest hilo project was part of the nest project (VEENENDAAL, BAKKER, & BLOCK, 2015). Shell structures had been a desired structure type for both architects and structural engineers due to its efficient load-bearing behavior. Grid-shells and spatial framework structures had continuously pushed the development of shell structures. A novel structure concept was then generated with also the inspiration of the natural cellular structures. A novel shell was finally built as a demonstrator of such a structure concept. With a dome which reaches a span of 5 meters and a height of 2.5 meters, the load-bearing capacity and the construction details of the cellular cavity structure were tested and evaluated. The research was based on a comprehensive analysis of the materials' application in the existing industrial and architectural design. The focus of the architectural analysis was the design procedure of the cellular cavity structure, including the form-finding process, the structural consideration of the stability problem of thin materials, the possible simple fabrication (Xiang, 2017). Shell structures were structurally efficient but difficult to manufacture and thus expansive. Actively bent grid shells and segmental plate shells could be alternatives. Dynamic relaxation method (DR) was applied in this research as an important numerical method. DR could handle not only form-finding problems but also geometrically nonlinear analysis. The dissertation consists of four parts. Part I was the introduction. Part II and Part III present both the form- Finding and analysis techniques of these two types of timber shell structures (Min Li, 2017). Unconventional building forms roofed with folded sheeting transformed elastically into shells. Modern and ecological materials determine the important shape and mechanical limitations of these forms. For effective design, it was necessary to use relevant software applications, where spatial reasoning was crucial for ordering the three-dimensional space by means of simplified engineering models. The study was a new insight into shaping free forms of buildings (Abramczyk & Prokopska , 2019). Worldwide floor area expected to almost double over the next 40 years. Most of the structural material in a building exists within the floors. Flooring system of textile-reinforced concrete shells with a foamed concrete fill had the potential to halve the amount of materials in the building's entire structure. These shells were unconventional in their low total depth, low reinforcement content and lack of rigid supports. In both cases, a hinged collapse mechanism was formed rather than sudden catastrophic failure, with positive implications for safety and robustness. The findings were published in the European Journal of Structural Engineering (Hawkins, Orr, Shepherd, & Ibell, 2019). It was focused on arches and shells that withstand the applied loads through compressive internal loading. The developed forms are suitable for construction in materials with substantial compressive strength. This was accomplished by corrugating the supporting edges of the shell so that a compressive load path can form within the depth of the supports. It was demonstrated that the obtained shapes were superior to non-form-found geometries in their material used and their horizontal pushover capacity. A second method for shells was developed that expands the 2D thrust line concepts to a 3D hanging net model approach. This method accounts for self-weight combined with seismic loads acting in any horizontal direction. The approach yields single-layer shells with varying thickness (Michiels T. , 2018). The method ensures that a compression load path exists to carry lateral earthquake accelerations by deriving shell geometries. It was demonstrated that the lateral capacity before cracking in the corrugated shell shapes was up to 79% higher than a non-form-found reference shell shapes. The paper provides a new approach for the conceptual design of safe corrugate shell structures in earthquake prone areas. It also proposes alternative designs that provide additional openings in the shell surface while maintaining similar seismic capacity (Michiels, Adriaenssens, & Dejong, 2019).Most structural systems in the West Bank were based on rather short or intermediate modules and were comprised of traditional framing of slabs, beams and columns. The dome-like roof that was presently an integral part of the skyline in Alteereh/Ramallah was a clear diversion from the traditional structural systems. Design and construction in this case was truly an indigenous all Palestinian exercise (H. Helou & Qadamani, 2019). Composite folded thin shell structure consists of concrete, expanded polystyrene foam (EPS), and glass-fiber reinforced polymer. The bearing capacity of the composite folded thin shell is 4.876 times that of the concrete thin shell. The presence of the bottom GFRP face sheet and the EPS core can effectively slow down the appearance of initial cracks in the concrete layer (Du, Liu, Zhou, & Uddin, 2019). A shape optimization method to maximize the non-linear buckling load using a genetic algorithm was proposed. The control points of a cubic spline were chosen as the design variables defining the height of the surface. The conventional approach of minimizing the total strain energy is not effective for improving the buckling strength. It was verified in the numerical examples that the proposed method can increase the Non-linear Buckling load maintaining the smoothness of the surfaces (Zhu, Ohsaki, Guo, & Zeng, 2020).

Materials and methods

Description of the methodology and Collecting Data

The data collection process and the type of data collected are described in this chapter. The data used in this research was collected according to theoretical values, model geometry, different loads, and buckling of shell to study the stability of shell roof structures under different load types. This research involved an extensive data collection effort that included a comprehensive description of analytical study using ANSYS Software.

- *Description of Shell Roof Structures*

Shell roofs are used for covering large span structures with a single story, e.g. assembly halls, recreation centers, theatres, factories, research labs etc. A shell roof is commonly used in public building because shell roof is aesthetically pleasing. When the inside of the building is required to be open without any walls or pillars then the shell roof is very useful than flat or even pitched roof. The shells roofs are lighter in weight and shell roofs are built with several materials such as in situ reinforced concrete, timber, steel sheets, ceramics, glass, plastics, hard board, lattice and composite structure. In shell roof construction, the slope of the roof and the curve of the arc must be carefully designed so that the building remains stable. Shell roof is not suitable where the roof is required to be at different levels, as the entire structure of the roof must be built at a single level. In shell roof construction, lighting and ventilation arrangement are also difficult to install. The design of shell roof is difficult, expensive and need skilled and experienced personals. A shell roof is relatively thin and does not require support beams. The costs of materials for these types of roofs are lower than the materials required for either a flat or a pitched roof.

- *Material Properties*

High-Tensile steel sheets with a nominal thickness from 4 mm to 20 mm were used to fabricate the modular units. This thickness was chosen as it is commonly available and is comparable to sheeting thickness in real modular units considering the scale difference between the laboratory and real modular units. High-Tensile steel sheets are suitable for the fabrication of the modular units' in future practical applications, due to their durability and ease to form different shapes. The material properties of the steel sheets were determined from tensile tests according to the Egyptian code (2007) to provide accurate material data for subsequent numerical modelling, as shown in table 1.

- *Geometry and Mechanical Properties of the Shells*

- Structure regular roof steel structures are supposed (the architectural plan is symmetrical for axes x and y).
- The radius of the roof from 750 mm to 4000 mm.
- Bay Span from 1m to 4m length and from 1m to 4m width
- F_{cu} / Yield Strength of Steel 500 kg/cm^2 / 4000 kg/cm^2
- Yield Strength of Steel - F_y (t/cm^2), $t \leq 40$ mm, and (Steel Str.) St 52 is 3.6 t/cm^2
- The loads consist of dead load, live load, internal wind pressure, and external wind load.
- Seismic loads were automatically generated according to Egyptian code as follows:
  - Ground acceleration (ag) = 0.15 g
  - Soil type "C"
  - Importance factor (I) = 1.0
  - Reduction factor (R) = 5.0
- All design and serviceability load combinations were automatically generated according to Egyptian code.

Table 1: Shows the details of Parametric study models

No.	Model	Radius	radius	Height	Thickness	Steel grade	Loading
1	R2000-r750-T4-V	2000	750	145.95	4	355	V
2	R2000-r750-T6-V	2000	750	145.95	6	355	V
3	R2000-r750-T8-V	2000	750	145.95	8	355	V
4	R2000-r750-T10-V	2000	750	145.95	10	355	V
5	R2000-r750-T12-V	2000	750	145.95	12	355	V
6	R2000-r1000-T4-V	2000	1000	267.949	4	355	V
7	R2000-r1000-T6-V	2000	1000	267.949	6	355	V
8	R2000-r1000-T8-V	2000	1000	267.949	8	355	V
9	R2000-r1000-T10-V	2000	1000	267.949	10	355	V
10	R2000-r1000-T12-V	2000	1000	267.949	12	355	V
11	R2000-r1500-T4-V	2000	1500	677.124	4	355	V
12	R2000-r1500-T6-V	2000	1500	677.124	6	355	V
13	R2000-r1500-T8-V	2000	1500	677.124	8	355	V
14	R2000-r1500-T10-V	2000	1500	677.124	10	355	V
15	R2000-r1500-T12-V	2000	1500	677.124	12	355	V
16	R2000-r1800-T4-V	2000	1800	1128.22	4	355	V
17	R2000-r1800-T6-V	2000	1800	1128.22	6	355	V
18	R2000-r1800-T8-V	2000	1800	1128.22	8	355	V
19	R2000-r1800-T10-V	2000	1800	1128.22	10	355	V
20	R2000-r1800-T12-V	2000	1800	1128.22	12	355	V
21	R2000-r2000-T4-V	2000	2000	2000	4	355	V
22	R2000-r2000-T6-V	2000	2000	2000	6	355	V
23	R2000-r2000-T8-V	2000	2000	2000	8	355	V
24	R2000-r2000-T10-V	2000	2000	2000	10	355	V
25	R2000-r2000-T12-V	2000	2000	2000	12	355	V
26	R2000-r750-T4-L	2000	750	145.95	4	355	L
27	R2000-r750-T6-L	2000	750	145.95	6	355	L
28	R2000-r750-T8-L	2000	750	145.95	8	355	L
29	R2000-r750-T10-L	2000	750	145.95	10	355	L
30	R2000-r750-T12-L	2000	750	145.95	12	355	L
31	R2000-r1000-T4-L	2000	1000	267.949	4	355	L
32	R2000-r1000-T6-L	2000	1000	267.949	6	355	L
33	R2000-r1000-T8-L	2000	1000	267.949	8	355	L
34	R2000-r1000-T10-L	2000	1000	267.949	10	355	L
35	R2000-r1000-T12-L	2000	1000	267.949	12	355	L
36	R2000-r1500-T4-L	2000	1500	677.124	4	355	L

37	R2000-r1500-T6-L	2000	1500	677.124	6	355	L
38	R2000-r1500-T8-L	2000	1500	677.124	8	355	L
39	R2000-r1500-T10-L	2000	1500	677.124	10	355	L
40	R2000-r1500-T12-L	2000	1500	677.124	12	355	L
41	R2000-r1800-T4-L	2000	1800	1128.22	4	355	L
42	R2000-r1800-T6-L	2000	1800	1128.22	6	355	L
43	R2000-r1800-T8-L	2000	1800	1128.22	8	355	L
44	R2000-r1800-T10-L	2000	1800	1128.22	10	355	L
45	R2000-r1800-T12-L	2000	1800	1128.22	12	355	L
46	R2000-r2000-T4-L	2000	2000	2000	4	355	L
47	R2000-r2000-T6-L	2000	2000	2000	6	355	L
48	R2000-r2000-T8-L	2000	2000	2000	8	355	L
49	R2000-r2000-T10-L	2000	2000	2000	10	355	L
50	R2000-r2000-T12-L	2000	2000	2000	12	355	L
51	R3000-r1150-T8-V	3000	1150	229.17	8	355	V
52	R3000-r1150-T10-V	3000	1150	229.17	10	355	V
53	R3000-r1150-T12-V	3000	1150	229.17	12	355	V
54	R3000-r1150-T14-V	3000	1150	229.17	14	355	V
55	R3000-r1150-T16-V	3000	1150	229.17	16	355	V
56	R3000-r1500-T8-V	3000	1500	401.92	8	355	V
57	R3000-r1500-T10-V	3000	1500	401.92	10	355	V
58	R3000-r1500-T12-V	3000	1500	401.92	12	355	V
59	R3000-r1500-T14-V	3000	1500	401.92	14	355	V
60	R3000-r1500-T16-V	3000	1500	401.92	16	355	V
61	R3000-r2000-T8-V	3000	2000	763.93	8	355	V
62	R3000-r2000-T10-V	3000	2000	763.93	10	355	V
63	R3000-r2000-T12-V	3000	2000	763.93	12	355	V
64	R3000-r2000-T14-V	3000	2000	763.93	14	355	V
65	R3000-r2000-T16-V	3000	2000	763.93	16	355	V
66	R3000-r2500-T8-V	3000	2500	1341.7	8	355	V
67	R3000-r2500-T10-V	3000	2500	1341.7	10	355	V
68	R3000-r2500-T12-V	3000	2500	1341.7	12	355	V
69	R3000-r2500-T14-V	3000	2500	1341.7	14	355	V
70	R3000-r2500-T16-V	3000	2500	1341.7	16	355	V
71	R3000-r3000-T8-V	3000	3000	3000	8	355	V
72	R3000-r3000-T10-V	3000	3000	3000	10	355	V
73	R3000-r3000-T12-V	3000	3000	3000	12	355	V
74	R3000-r3000-T14-V	3000	3000	3000	14	355	V
75	R3000-r3000-T16-V	3000	3000	3000	16	355	V
76	R3000-r1150-T8-L	3000	1150	229.17	8	355	L
77	R3000-r1150-T10-L	3000	1150	229.17	10	355	L
78	R3000-r1150-T12-L	3000	1150	229.17	12	355	L
79	R3000-r1150-T14-L	3000	1150	229.17	14	355	L
80	R3000-r1150-T16-L	3000	1150	229.17	16	355	L
81	R3000-r1500-T8-L	3000	1500	401.92	8	355	L
82	R3000-r1500-T10-L	3000	1500	401.92	10	355	L
83	R3000-r1500-T12-L	3000	1500	401.92	12	355	L
84	R3000-r1500-T14-L	3000	1500	401.92	14	355	L
85	R3000-r1500-T16-L	3000	1500	401.92	16	355	L
86	R3000-r2000-T8-L	3000	2000	763.93	8	355	L
87	R3000-r2000-T10-L	3000	2000	763.93	10	355	L
88	R3000-r2000-T12-L	3000	2000	763.93	12	355	L
89	R3000-r2000-T14-L	3000	2000	763.93	14	355	L
90	R3000-r2000-T16-L	3000	2000	763.93	16	355	L
91	R3000-r2500-T8-L	3000	2500	1341.7	8	355	L
92	R3000-r2500-T10-L	3000	2500	1341.7	10	355	L
93	R3000-r2500-T12-L	3000	2500	1341.7	12	355	L
94	R3000-r2500-T14-L	3000	2500	1341.7	14	355	L
95	R3000-r2500-T16-L	3000	2500	1341.7	16	355	L
96	R3000-r3000-T8-L	3000	3000	3000	8	355	L
97	R3000-r3000-T10-L	3000	3000	3000	10	355	L
98	R3000-r3000-T12-L	3000	3000	3000	12	355	L
99	R3000-r3000-T14-L	3000	3000	3000	14	355	L
100	R3000-r3000-T16-L	3000	3000	3000	16	355	L
101	R4000-r1500-T12-V	4000	1500	291.9	12	355	V
102	R4000-r1500-T14-V	4000	1500	291.9	14	355	V

103	R4000-r1500-T16-V	4000	1500	291.9	16	355	V
104	R4000-r1500-T18-V	4000	1500	291.9	18	355	V
105	R4000-r1500-T20-V	4000	1500	291.9	20	355	V
106	R4000-r2000-T12-V	4000	2000	535.898	12	355	V
107	R4000-r2000-T14-V	4000	2000	535.898	14	355	V
108	R4000-r2000-T16-V	4000	2000	535.898	16	355	V
109	R4000-r2000-T18-V	4000	2000	535.898	18	355	V
110	R4000-r2000-T20-V	4000	2000	535.898	20	355	V
111	R4000-r2500-T12-V	4000	2500	877.5	12	355	V
112	R4000-r2500-T14-V	4000	2500	877.5	14	355	V
113	R4000-r2500-T16-V	4000	2500	877.5	16	355	V
114	R4000-r2500-T18-V	4000	2500	877.5	18	355	V
115	R4000-r2500-T20-V	4000	2500	877.5	20	355	V
116	R4000-r3200-T12-V	4000	3200	1600	12	355	V
117	R4000-r3200-T14-V	4000	3200	1600	14	355	V
118	R4000-r3200-T16-V	4000	3200	1600	16	355	V
119	R4000-r3200-T18-V	4000	3200	1600	18	355	V
120	R4000-r3200-T20-V	4000	3200	1600	20	355	V
121	R4000-r4000-T12-V	4000	4000	4000	12	355	V
122	R4000-r4000-T14-V	4000	4000	4000	14	355	V
123	R4000-r4000-T16-V	4000	4000	4000	16	355	V
124	R4000-r4000-T18-V	4000	4000	4000	18	355	V
125	R4000-r4000-T20-V	4000	4000	4000	20	355	V
126	R4000-r1500-T12-L	4000	1500	291.9	12	355	L
127	R4000-r1500-T14-L	4000	1500	291.9	14	355	L
128	R4000-r1500-T16-L	4000	1500	291.9	16	355	L
129	R4000-r1500-T18-L	4000	1500	291.9	18	355	L
130	R4000-r1500-T20-L	4000	1500	291.9	20	355	L
131	R4000-r2000-T12-L	4000	2000	535.898	12	355	L
132	R4000-r2000-T14-L	4000	2000	535.898	14	355	L
133	R4000-r2000-T16-L	4000	2000	535.898	16	355	L
134	R4000-r2000-T18-L	4000	2000	535.898	18	355	L
135	R4000-r2000-T20-L	4000	2000	535.898	20	355	L
136	R4000-r2500-T12-L	4000	2500	877.5	12	355	L
137	R4000-r2500-T14-L	4000	2500	877.5	14	355	L
138	R4000-r2500-T16-L	4000	2500	877.5	16	355	L
139	R4000-r2500-T18-L	4000	2500	877.5	18	355	L
140	R4000-r2500-T20-L	4000	2500	877.5	20	355	L
141	R4000-r3200-T12-L	4000	3200	1600	12	355	L
142	R4000-r3200-T14-L	4000	3200	1600	14	355	L
143	R4000-r3200-T16-L	4000	3200	1600	16	355	L
144	R4000-r3200-T18-L	4000	3200	1600	18	355	L
145	R4000-r3200-T20-L	4000	3200	1600	20	355	L
146	R4000-r4000-T12-L	4000	4000	4000	12	355	L
147	R4000-r4000-T14-L	4000	4000	4000	14	355	L
148	R4000-r4000-T16-L	4000	4000	4000	16	355	L
149	R4000-r4000-T18-L	4000	4000	4000	18	355	L
150	R4000-r4000-T20-L	4000	4000	4000	20	355	L

The main components of the research methodology include the review of scientific literature, data collection, analysis of data, and analytical studies. Research literature has been reviewed to identify the research gaps in the current research and provide a framework for positioning research endeavors. By this information, a comprehensive data collection instrument was developed.

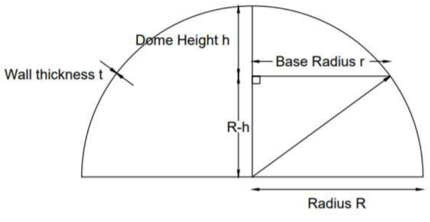

Fig 1: Shows the geometry for models

- R: Radius (mm)
- r: radius (mm)
- h: Height (mm)
- T: Thickness (mm)
- R3-r1-T4-S355-V: Radius 3000-radius 1000-Thicckness 4mm- Grade S355- Load type Vertical

- V: Vertical (Dead load and Live load)
- L: Lateral load (Seismic and Wind)

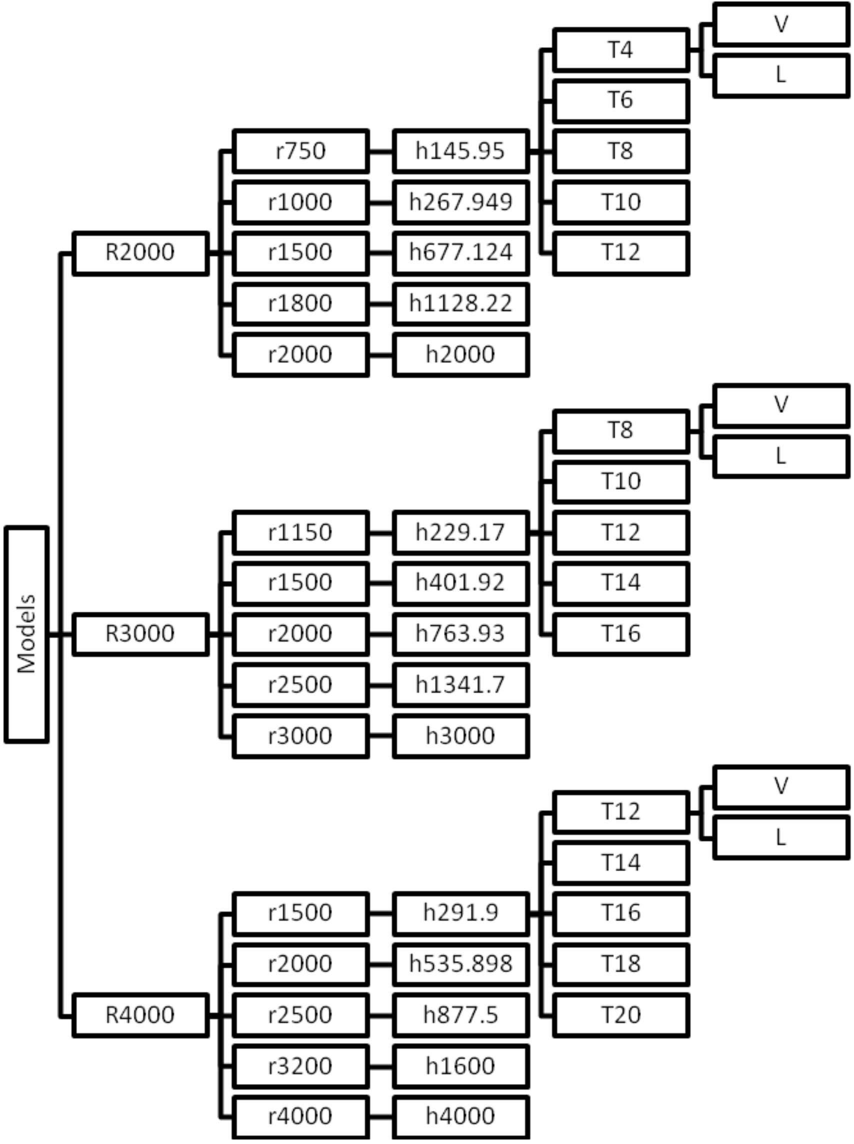

Fig 2: Classification for the parameters

Results

This section presents the results from the analytical study and discuss these results.

Table 2: Shows the results for stresses and deformation - R2000-r750-T (4-12)-VL

T4		T6		T8		T10		T12	
Pressure MPa	**Deformation mm**	**Pressure MPa**	**Deformation mm**	**Pressure MPa**	**Deformation mm**	**Pressure MPa**	**Deformation mm**	**Pressure MPa**	**Deformation mm**
0.055	0.37672	0.055	0.25554	0.055	0.19435	0.055	0.15768	0.055	0.13376
0.11	0.75346	0.11	0.51109	0.11	0.38873	0.11	0.3154	0.11	0.26754
0.165	1.1302	0.165	0.76665	0.165	0.5831	0.165	0.47311	0.165	0.40132
0.22	1.5069	0.22	1.0222	0.22	0.77748	0.22	0.63082	0.22	0.5351
0.275	1.8837	0.275	1.2778	0.275	0.97185	0.275	0.78853	0.275	0.66888
0.33	2.2604	0.33	1.5333	0.33	1.1662	0.33	0.94624	0.33	0.80266
0.385	2.6372	0.385	1.7889	0.385	1.3606	0.385	1.104	0.385	0.93644
0.44	3.0139	0.44	2.0444	0.44	1.555	0.44	1.2617	0.44	1.0702
0.495	3.3906	0.495	2.3	0.495	1.7494	0.495	1.4194	0.495	1.204
0.55	3.7674	0.55	2.5556	0.55	1.9437	0.55	1.5771	0.55	1.3378
0.605	4.1441	0.605	2.8111	0.605	2.1381	0.605	1.7348	0.605	1.4716
0.66	4.5209	0.66	3.0667	0.66	2.3325	0.66	1.8925	0.66	1.6054
0.715	4.8976	0.715	3.3222	0.715	2.5269	0.715	2.0502	0.715	1.7391
0.77	5.2743	0.77	3.5778	0.77	2.7212	0.77	2.2079	0.77	1.8729
0.825	5.6511	0.825	3.8333	0.825	2.9156	0.825	2.3656	0.825	2.0067
0.88	6.0278	0.88	4.0889	0.88	3.11	0.88	2.5234	0.88	2.1405

0.935	6.4049	0.935	4.3444	0.935	3.3044	0.935	2.6811	0.935	2.2743
0.99	6.7819	0.99	4.6	0.99	3.4987	0.99	2.8388	0.99	2.408
1.045	7.1594	1.045	4.8556	1.045	3.6931	1.045	2.9965	1.045	2.5418
1.1	7.5434	1.1	5.1111	1.1	3.8875	1.1	3.1542	1.1	2.6756
1.155	7.927	1.155	5.3667	1.155	4.0819	1.155	3.3119	1.155	2.8094
1.21	8.3105	1.21	5.6222	1.21	4.2762	1.21	3.4696	1.21	2.9432
1.265	8.7316	1.265	5.8778	1.265	4.4706	1.265	3.6273	1.265	3.0769
1.32	14.321	1.32	6.1335	1.32	4.665	1.32	3.785	1.32	3.2107
1.375	22.314	1.375	6.3893	1.375	4.8594	1.375	3.9428	1.375	3.3445
1.43	33.377	1.43	6.6451	1.43	5.0537	1.43	4.1005	1.43	3.4783
1.485	60.744	1.485	6.9008	1.485	5.2481	1.485	4.2582	1.485	3.6121
1.54	89.622	1.54	7.1584	1.54	5.4425	1.54	4.4159	1.54	3.7458
1.595	119.52	1.595	7.4192	1.595	5.6369	1.595	4.5736	1.595	3.8796
1.65	149.76	1.65	7.6797	1.65	5.8312	1.65	4.7313	1.65	4.0134
1.705	180.19	1.705	7.9399	1.705	6.0257	1.705	4.889	1.705	4.1472
1.76	210.69	1.76	8.2	1.76	6.2203	1.76	5.0467	1.76	4.281
1.815	241.29	1.815	8.4607	1.815	6.4149	1.815	5.2045	1.815	4.4148
1.87	272.7	1.87	8.743	1.87	6.6095	1.87	5.3622	1.87	4.5485
		1.925	9.3137	1.925	6.804	1.925	5.5199	1.925	4.6823
		1.98	14.401	1.98	6.9984	1.98	5.6776	1.98	4.8161
		2.035	19.612	2.035	7.1967	2.035	5.8353	2.035	4.9499
		2.09	25.131	2.09	7.3955	2.09	5.9932	2.09	5.0837
		2.145	32.688	2.145	7.5941	2.145	6.1511	2.145	5.2175
		2.2	51.223	2.2	7.7924	2.2	6.309	2.2	5.3513
		2.255	69.924	2.255	7.9907	2.255	6.4669	2.255	5.4851
		2.31	89.124	2.31	8.1889	2.31	6.6247	2.31	5.6189
		2.365	108.98	2.365	8.3878	2.365	6.7826	2.365	5.7526
		2.42	129.09	2.42	8.5926	2.42	6.9404	2.42	5.8864
		2.475	149.36	2.475	8.8132	2.475	7.1	2.475	6.0204
		2.53	169.73	2.53	9.0525	2.53	7.2617	2.53	6.1543
		2.585	190.11	2.585	10.376	2.585	7.4232	2.585	6.2883
		2.64	210.55	2.64	14.452	2.64	7.5847	2.64	6.4222
		2.695	231.07	2.695	18.428	2.695	7.7461	2.695	6.5561
		2.75	251.73	2.75	22.447	2.75	7.9074	2.75	6.6899
		2.805	273.06	2.805	26.607	2.805	8.0685	2.805	6.8238
				2.86	32.273	2.86	8.2295	2.86	6.9576
				2.915	46.129	2.915	8.391	2.915	7.0921
				2.97	60.635	2.97	8.5529	2.97	7.2294
				3.025	74.738	3.025	8.7275	3.025	7.3667
				3.08	89.056	3.08	8.9086	3.08	7.5039
				3.135	103.79	3.135	9.0922	3.135	7.641
				3.19	118.82	3.19	9.3095	3.19	7.778
				3.245	134.04	3.245	11.22	3.245	7.9148
				3.3	149.4	3.3	14.46	3.3	8.0515
				3.355	164.83	3.355	17.721	3.355	8.1882
				3.41	180.27	3.41	20.977	3.41	8.3248
				3.465	195.73	3.465	24.255	3.465	8.4616
				3.52	211.19	3.52	27.58	3.52	8.5985
				3.575	226.69	3.575	32.175	3.575	8.7426
				3.63	242.27	3.63	42.763	3.63	8.8914
				3.685	257.88	3.685	54.735	3.685	9.0423
				3.74	274.28	3.74	66.382	3.74	9.1927
						3.795	77.766	3.795	9.3417
						3.85	89.161	3.85	9.5136
						3.905	100.79	3.905	11.862
						3.96	112.65	3.96	14.479
						4.015	124.72	4.015	17.226
						4.07	136.94	4.07	20.035
						4.125	149.27	4.125	22.828
						4.18	161.69	4.18	25.608
						4.235	174.14	4.235	28.391
						4.29	186.62	4.29	32.293
						4.345	199.12	4.345	40.631
						4.4	211.62	4.4	50.566
						4.455	224.15	4.455	60.623
						4.51	236.73	4.51	70.442

4.565	249.32	4.565	80.085
4.62	262.05	4.62	89.666
4.675	275.3	4.675	99.311
4.73	297.89	4.73	109.07
		4.785	118.98
		4.84	129.01
		4.895	139.17
		4.95	149.44
		5.005	159.79
		5.06	170.18
		5.115	180.62
		5.17	191.09
		5.225	201.58
		5.28	212.08
		5.335	222.62
		5.39	233.2
		5.445	243.79
		5.5	254.39

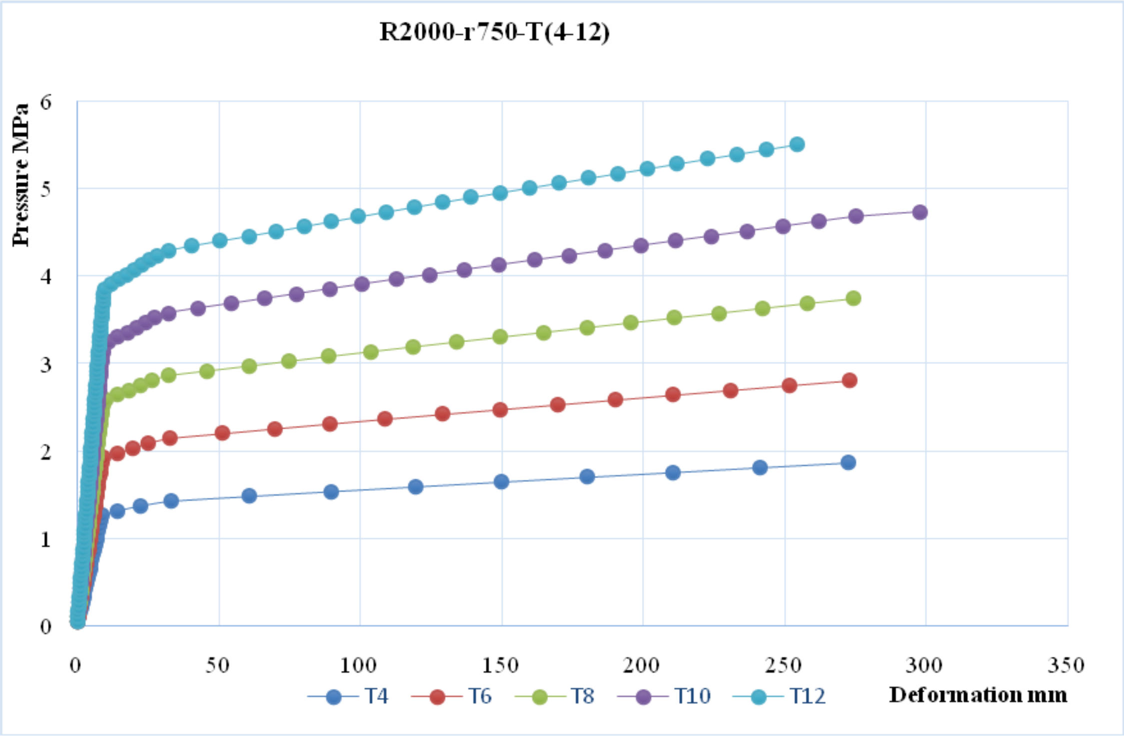

Fig 3: Shows the results for stresses and deformation

Conclusions

The main components of the research methodology include the review of scientific literature, data collection, analysis of data, and analytical studies. Research literature has been reviewed to identify the research gaps in the current research and provide a framework for positioning research endeavors. By this information, a comprehensive data collection instrument was developed. High-Tensile steel sheets with a nominal thickness from 4 mm to 20 mm were used to fabricate the modular units. This thickness was chosen as it is commonly available and is comparable to sheeting thickness in real modular units considering the scale difference between the laboratory and real modular units. High-Tensile steel sheets are suitable for the fabrication of the modular units' in future practical applications, due to their durability and ease to form different shapes. Two main alternatives were introduced, the complete Lagrangian and the modified Lagrangian. These two options are used for shell elements. If the system deforms in the finite model, the local deflections are large enough so that the strains are no longer small. The local element stiffness changes as a result of the geometry modification of the product. No assumptions are made about the importance of the strains. In comparison to the aforementioned, residual stress is not used in the research solution.

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