Numerical Code-Based Assessment of Live Load Patterning Effect on Bending Moment Envelopes in Reinforced Concrete Beam-Column Frames

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ABSTRACT

This study evaluates the influence of slab idealisation and live-load pattern on the bending-moment response of a continuous reinforced-concrete subframe using Robot Structural Analysis Professional (RSAP), using manual analysis to BS 8110 as the reference. The objectives were to establish mesh convergence for the analytical shell model, compare the internal continuous beam and column responses of the manual, cladding and analytical shell models, and quantify their differences. Mesh refinement showed that the shell solution was practically converged at 0.25 m; refinement from 0.25 to 0.125 m changed the span 1–2 and interior-support moments by only 0.10% and 0.13%, respectively. The cladding model closely reproduced the manual beam results, with differences of 2.76% for span 1–2, 5.35% for span 2–3 and 0.48% at the interior support. In contrast, the shell model produced reductions of 18.49%, 28.59% and 28.02%, respectively. The shell model also increased the interior-column axial load by 23.06%, while reducing the column top moment by 16.90%. The findings indicate that the observed differences are associated with different structural load-transfer mechanisms rather than mesh refinement alone. The study recommends converged FE models with independent equilibrium and benchmark checks and selection of slab idealisation according to the structural behaviour being represented.

Keywords: *live-load pattern; slab idealisation; Robot Structural Analysis; cladding model; analytical shell finite element; mesh convergence; bending-moment envelope; BS 8110.*

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INTRODUCTION

Many structural elements encountered in real life have complex geometry, loadings and material properties. It is for this reason that there are no always analytical solutions to these problems. As such, the engineer has to resort to numerical methods in order to solve the problems at hand (Logan, 2022).

The use of structural analysis software is very important in the analysis and design of reinforced concrete structures. However, the reliability of a computed response largely depends on the structural idealisation, loading assumptions, element formulation and numerical discretisation used by the engineer. Słota and Wosatko (2025) maintained that it is the responsibility of engineers to independently verify the numerical outputs generated by any structural analysis software using benchmark problems. They also highlighted the importance of solution convergence, modelling options and beam-plate interaction in finite-element analysis.

Pechorskaya et al. (2021) reported that the finite-element solution involves meshing and load distribution through the mesh while considering the relative stiffness of the mesh. They also highlighted that modelling a concrete slab using shell elements in Autodesk Robot Structural Analysis Professional (RSAP), makes the slab to possess out-of-plane stiffness. Thus, the slab participates in carrying loads through bending and that makes the relative stiffness of the structural component relevant in its structural response. It is for this reason that the response obtained from a stiffness-based shell idealisation of a slab may differ from that obtained when the slab load is transferred to supporting members using a tributary idealisation (Pechorskaya et al., 2021; Słota & Wosatko, 2025). Reinforced concrete beams and frames subjected to live loads are more affected by the slab idealisation adopted in RSAP. Live load unlike permanent load, may be applied to different spans during the building's life span. As such, code-based pattern loadings described in different design codes are carried out to identify the most adverse combination that produce critical positive and negative moment. Yadav and Garg (2017) found that patterned live loading produce substantially greater bending moment that conventional all-span gravity loading in their multi-space frame study.

Also, finite-element studies show that numerical output is a function of the way slabs, beams and their interfaces are represented. Mikula and Szolomicki (2019) reported substantial differences in reinforced concrete floor-slab deflection between three finite element (FE) packages despite the fact that analyses followed the same standards and were based on FE formulations. They attributed the differences to treatment of shrinkage, creep, minimum reinforcement, non-linear analysis and tension stiffening. In a recent study by Słota and Wosatko (2025), they demonstrated using benchmark problems, that the reliability of finite element results is influenced by mesh convergence, slab moments near supports and beam-plate interaction.

Other studies highlight the need for controlled verification. Kajja et al. (2024) reported that a simple reinforced concrete beam model in RSAP can replicate analytical beam behaviour with insubstantial differences under controlled loading. Further, Shamsi and Sümer (2024) highlighted that mesh size and other finite element modelling parameters can substantially influence reinforced frame response. Similarly, Pechorskaya et al. (2021) also reported differences between RSAP and ETABS software results for a multi-storey reinforce concrete frame. They attributed the differences to element presentation, meshing and the treatment of relative stiffness. The main problem addressed by this study is to identify the mechanical and numerical causes of difference between bending moment envelopes of subframe analysis using one-way claddings and subframe analysis using shell elements. In both cases the slabs are modelled with live loads applied separately on each span. Hardy Cross moment distribution is used to analyse the subframe based on simplified load patterns as per BS8110. The bending moment envelopes are then compared to those obtained from the two RSAP models. The research separates three potentially confounding factors: live load arrangement, slab idealization/load transfer mechanism and finite element mesh.

Literature Review and Research Gap

Live Load Pattern Loading and Continuous Member Response

Pattern loading is important in the elastic analysis of continuous reinforced members because different arrangements of live loads on multi-span members produce different structural response. The BS 8110 approach identifies critical arrangements involving all spans (1.4 G_k +1.6 Q_k) and alternate loaded spans, with maximum (1.4 G_k +1.6 Q_k) and minimum design load (1.0 G_k) applied to loaded and unloaded spans as appropriate. This principle is generally consistent with the findings of Yadav and Garg (2017), who demonstrated that five-bay by five-bay frame generated greater beam bending moment under different types of chessboard patterned live loads than under the conventional all-span gravity loading. They also reported that the effect was more pronounced for bending moment than beam shear or axial load. Their work did use a frame model without an explicit shell slab FE representation. Also, the study did not combine influence-line/code pattern concepts with plate stiffness and load redistribution. Further, the study focused on load arrangement but did not distinguish it from the slab load-transfer mechanism. Solarczyk and Ambroziak (2018) reported that different live-load patterns produced appreciable differences in the calculated bending moments of the analysed flat-slab structure. The study showed that the 20 × 20 cm finite-element mesh provided satisfactory convergence, while further mesh refinement substantially increased computational time and output-file size without significant improvement in the results. Also, the stated that the chessboard pattern generated bending moments closest to those obtained from loading individual panes, while single slabs and banded loading produced comparatively larger differences.

Finite Element Modelling of Reinforced Frame and Slab

Mikula and Szolomicki (2019) compared four reinforced concrete floor-slab models using RSAP, ABC Plate and

Dlubal RFEM packages. In this research they considered different support conditions, cracking, rheological effects and mesh-related issues. They reported that despite the use of FE-based approaches and codes-based procedures, the packages produced different deflection results. The authors concluded that numerical results should be confirmed by experimental methods and that slab behaviour is a function material and modelling assumptions.

More recently, Haque (2025) demonstrated that the numerical response of reinforced concrete floor system is a function of slab stiffness. In the study, he made use of four-node rectangular plate elements in ETABS, varied span length of a two-way slab, live load and central opening size and reported substantial changes in the deflection, strain and stress as slab stiffness changes. He did not model any reinforced concrete frame.

Shamsi and Sümer (2024) worked on non-linear cyclic reinforced concrete frame modelling in ABAQUS software. They investigated dilation angle, stiffness recovery, friction coefficient and mesh size. They concluded that numerical response could change substantially when FE modelling parameters change. Further, they reported that mesh sensitivity must be assessed explicitly.

Verification of RSAP and Other Structural Analysis Software

Kajja et al. (2024) used RSAP to investigate a reinforced concrete beam subjected to different inclination angles and compared the results with the analytical relationships. The study reported that at 0 angle of rotation, numerical bending moments were close to the analytical values with small differences. Similarly, Słota and Wosatko (2025), through several benchmark problems involving in-plane and out-of-plane bending, extended this verification philosophy. Their study emphasised that before an engineer uses a software to analyse complex structural models, they independently verify it using simple benchmark problems.

Pechorskaya et al. (2021) compared RSAP and ETABS in the analysis of a thirty-storey reinforced concrete building. They found out that RSAP produced higher forces and moments. They attributed the differences to element formulation, mesh generation and treatment of slab and link-beam behaviour.

Manual versus FE-Based Analysis

In a study by Latief and Eassa (2024), they compared manual calculations with RSAP in the analysis of a six-storey building and reported generally similar results under gravity loading. However, larger differences occurred when seismic and wind actions were applied. The authors emphasised the importance of manual structural analysis skills for checking computer-generated responses. The research did not explicitly discuss on pattern loading, slab idealisation and mesh convergence.

Research Gap

The reviewed literature establishes that live load patterning affects continuous-member moments, that shell/plate stiffness changes slab and frame response, and that finite-element mesh and modelling assumptions influence numerical results. What remains insufficiently established is the combined effect of these mechanisms on the bending-moment envelope of continuous reinforced-concrete beam–column frames. In particular, there is a methodological gap in directly comparing a BS 8110 manual/subframe reference with an RSAP tributary/cladding representation and an RSAP shell representation under the same span-by-span live load patterns.

Aim

The aim of this study is to carry out numerical code-based assessment of live load patterning effect on bending moment envelopes in reinforced concrete beam-column frames in Autodesk Robot Structural Analysis Professional 2023 software.

Objectives

I. To determine the critical positive and negative bending moment using simplified manual/subframe under the BS 8110 live load patterns.
II. To develop an equivalent RSAP tributary-load/cladding model in which each slab is loaded independently and its load is transferred to the supporting RC frame
III. To develop an RSAP shell-slab finite element model using the same structural geometry, material properties, load magnitudes and live load patterns as the tributary-load model.
IV. To determine the effect on finite-element mesh size on the calculated beam and column responses.
V. To compare the positive and negative beam and column bending moment envelopes obtained from manual analysis, RSAP cladding and RSAP shell model
VI. To quantify differences using absolute error, percentage error and response ratios.

Materials and Methods

Materials

The structure in Figure 1 was drawn using Autodesk AutoCAD 2023, modelled and analysed in Autodesk Robot Structural Analysis Professional 2023 on a core i5 PC with 8 gb RAM. AutoCAD is the industry (architecture, engineering and construction) standard CAD program for 2-dimensional drafting (Maina, 2018). RSAP is a very powerful finite element package for general purpose structural engineering analysis and design. It can carry out different analysis types such as harmonic, modal, pushover, dynamic, footfall, etc.). Further, different

Table 1: Structural Configuration

Parameter	Baseline value	Purpose
Number of bays	2	Provides continuous interior spans and supports pattern loading
Bay length	6.0 m, 4.0 m	Representative medium-span floor grid
Storeys	3	Allows column response to be evaluated at several levels. Only one subframe is considered.
Storey height	3.5 m	Regular vertical geometry
Frame spacing (braced)	4.0 m	Regular frame spacing
Slab system	1-Way RC slab	Allows analytical shell load redistribution in RSAP Model S. Model C uses tributary loading similar to the one used in manual analysis.
Support condition	Fixed/monolithic base; rigid beam–column joints	Consistent frame idealisation
Analysis type	Linear elastic gravity analysis	Isolates load arrangement and numerical effects

Table 2: Material, Section Properties and Loading

Component	Baseline property	Value used for controlled study
Concrete	Characteristic compressive strength	25 MPa
Concrete	Elastic modulus	Based on adopted code/material model and held constant
Concrete	Poisson ratio	0.17
Concrete	Unit weight	24 kN/m^3
Reinforcement	Characteristic yield strength	410 MPa
Beam	Section	300 × 700 mm
Column	Section	300 × 400 mm
Slab	Thickness	200 mm.
Dead Load (including slab self-weight	10 kN /m^2	
Live load (to be placed on each span separately)	15 kN / m^2	To simulate all possible load patterns in RSAP. This is done by doing automatic combination to BS 8110 in the software.

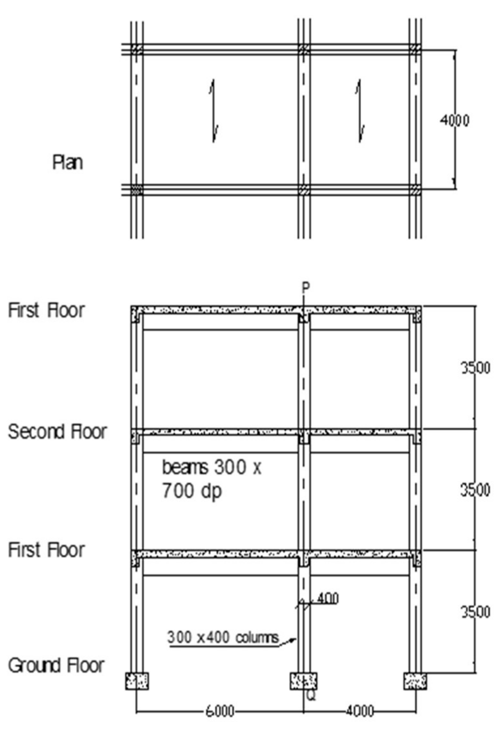

Figure 1: Section through the frame

materials can be analysed and designed using international codes. It takes a lot of practice in order to know to navigate through Further, different materials can be analysed and designed using international codes. It takes a lot of practice in order to know to navigate through the program efficiently since the standard method of interacting with it differ significantly with the typical windows style applications. Thus, confusion may arise during using the program (Marsh, 2014)

In the present study, it is required to compute the moments at the first-floor beam framing into the centre column along line PQ together with its axial load and moment at ULS. The model in Figure 1 is taken from (Mosley & Bungey, 1990). The model is a heavily loaded industrial structure concrete carrying a total slab dead (including self-weight) and live loads of 10 kN/m^2 and 15 kN/m^2 respectively. The frames are braced against lateral forces and spaced at 4 m centres. The slab thickness is 200 mm, and the beams have 300 x 700 mm cross sections. The columns, having cross section of 300 mm x 400 mm, are fixed to their bases. The grade of steel and concrete used are 25 MPa and 410 MPa respectively. Tables 1 and Table 2 show the structural configuration and material, section properties and loadings respectively. Mosley & Bungey, (1990) considered all the slabs to be one-way in the direction of the frame centres. This is also adopted in the RSAP cladding model.

The study is designed as a controlled numerical experiment. The principal independent variables are the load arrangement and slab idealisation, while the principal dependent variables are beam bending moments, column forces/moments and computational effort. The numerical strategy follows the verification philosophy advocated by Kajja et al. (2024) and Słota and Wosatko (2025), while the mesh-sensitivity procedure is informed by Mikula and Szolomicki (2019) and Shamsi and Sümer (2024).

Method

Load cases and BS 8110 combinations

The characteristic dead load, Gk = 10 kN/m^2, consists of structural self-weight and superimposed dead loads such as finishes and fixed partitions where applicable. The characteristic live load, Qk = 15 kN/m^2, is applied as a surface load to the individual slabs or as an equivalent tributary line load in the cladding/manual representations. The study retains separate load cases for self-weight, superimposed dead load and live load. This is essential because equivalent pattern cases must be created consistently in both the cladding and shell models.

Loading patterns

BS 8110 pattern loading is represented by a complete set of span-by-span arrangements sufficient to identify the critical positive and negative bending moments. The basic arrangements include all spans loaded and alternate spans loaded with (1.4 G_k + 1.6 Q_k), with the remaining spans carrying the appropriate minimum dead-load of (1.4 G_k). RSAP does not have automatic load pattern distribution because live loads on continuous beams or slabs defined in the model of a structure act as applied load. If a user wants load pattern similar to what the code specifies, they must apply live loads separately on individual slabs (Kosakowski, 2014). Alternatively, in order to save the computation time, the live loads can be applied alternatively in a chess mat format using only two live loads (Mustafahasenow, 2017)

When each span is loaded with its own live load in the program, the number of load patterns generated in RSAP is 138 which more than the 3 patterns described in BS 8110. This is so because the software produced all the possible combination of dead and live loads on the spans. Pattern loading arrangement in the software is particularly important because it allows for easy comparison between manual subframe analysis envelope with those from the RSAP models; this is despite the fact that the number of cases generated by the software is substantially higher than the manual the ones described in the code.

RSAP Models

Two RSAP models are proposed. Model C, shown in Figure 2, is the tributary/cladding representation in which slab loads are represented as area loads that are transferred to supporting beams according to the one-way x load-distribution/tributary idealisation. This model has no slabs because cladding is just an object for simulating slab loads based on one-way or two-way actions on the frames. Model S, shown in Figure 3 is the analytical shell representation in which there are slabs which explicitly discretised using finite elements and participate in the structural stiffness matrix. Model S does not distribute tributary loadings on the slabs. The frame members remain identical in both models.

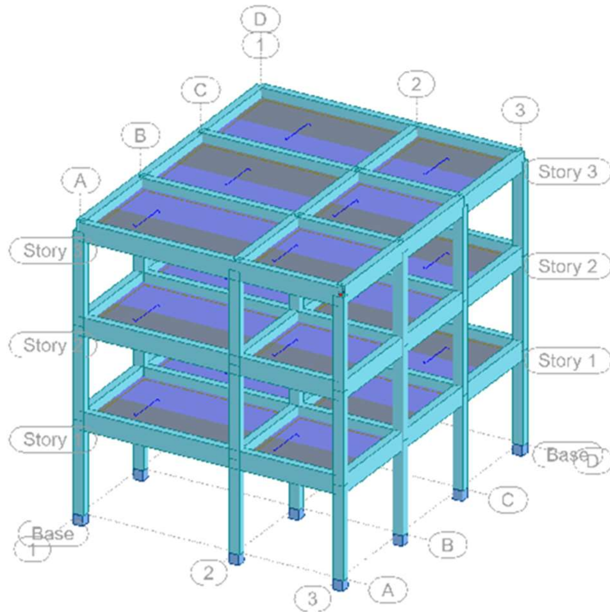

Figure 2: RSAP Model C: Reinforced Concrete Frame with One-Way X Cladding Element Showing the Spanning Direction

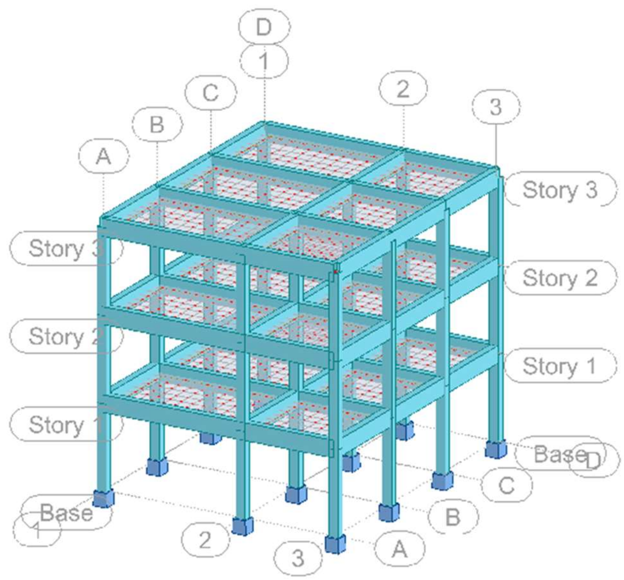

Figure 3: RSAP Model S: Reinforced Concrete Frame with Analytical Shell Element

In RSAP floor-load distribution is dependent on the selected panel calculation model. When analytical finite-element load transfer is selected, the program generates a finite-element mesh and distributes the applied loads through the finite-element model. RSA also provides simplified one-way and two-way load-transfer models based on triangular and trapezoidal distribution. These load-transfer options are independent of the finite-element type and can be combined with shell finite elements or used without finite elements. In particular, the shell analytical finite-element model represents the floor using shell finite elements, whereas the simplified models determine load transfer using idealised tributary-area distributions. Thus, the finite-element mesh represents the structural panel, whereas the selected load-transfer procedure governs how the applied floor load is distributed to its supports (Autodesk, 2023a, 2023b).

The difference between the models is very important. In the shell representation, the slab has out-of-plane flexural stiffness and participates in load redistribution, whereas the tributary representation is intended to reproduce the load path underlying conventional manual analysis. Pechorskaya et al. (2021) similarly noted that shell modelling in RSAP can allow the slab to share load through flexure because the relative stiffness of structural components is considered.

For the purpose of the research all modelling options unrelated to the experimental variables are held constant. These include material properties, member releases, support conditions, self-weight, geometric offsets, connectivity and analysis solver settings. The number of load patterns generated in RSAP when each span is loaded with a separate live load is more than what is presented in BS 8110. This is so because the software produced all the possible combination of dead and live loads on the spans.

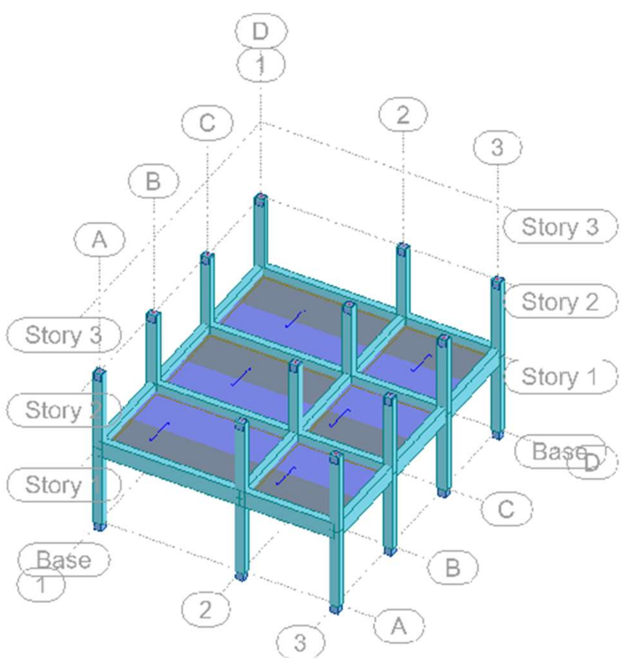

Figure 4: Model C substructure for frame analysis

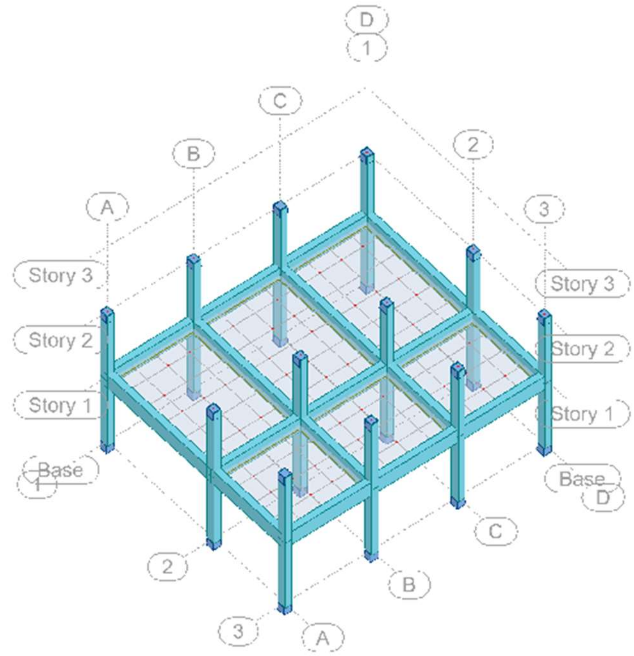

Figure 5: Model S substructure for frame analysis

From both models, three-dimensional substructures between stories 1 and 2 are extracted and saved as separate substructures which are then analysed to BS 8110 by selecting the code in the job preferences of RSAP. Figure 4 and Figure 5 show the respective submodels. The subframes along gridline C for each model is opened in new window to show the members responses. Table columns from RSAP were then used to extract the exact bending moment envelopes for each of the subframe of the models. The analysis bending moment envelope (as per BS 8110 simplified load pattern) using moment distribution method is then compared Model C. For Model S comparison is made after each mesh refinement to achieve numerical convergence.

Mesh refinement and convergence criterion

Mesh refinement is necessary because finite-element results can change with element size. Shamsi and Sümer (2024) demonstrated that mesh size can affect global RC-frame response, while Słota and Wosatko (2025) showed that benchmark solutions should be approached through systematic convergence checks. The shell model was therefore be analysed using a sequence of progressively refined meshes.

The convergence criterion utilised is this research is percentage change in the envelope response between two successive mesh refinements be less than 2%. The final mesh is selected from the first mesh that satisfies the prescribed criterion without unnecessary computational expense. The mesh convergence criterion used is based on the maximum moment at support 2 and maximum moment in spans 1-2 and 2-3 of the subframe.

The error mesh percentage necessary for convergence is computed using the equation below

$$Error\ mesh(\%) = \frac{R_i - R_{i-1}}{R_i} \times 100$$

Where

R_i = response at the current mesh

R_{i-1} = response at the current preceding coarser mesh

Validation

The continuous subframe along gridline C response envelope for Model C is compared against the BS 8110/manual reference for the corresponding tributary load idealisation.

Error Metrics

The main comparison is based on bending moment envelope. For the subframe along gridline C of our model, maximum positive moment and maximum negative support moment envelope are extracted and the following metrics are recommended:

$$Absolute\ error = R_{model\ C} - R_{Manual/BS8110}$$

$$Percentage\ error = \frac{R_{model\ C} - R_{Manual}}{R_{Manual/BS8110}} \times 100$$

$$Response\ ratio = \frac{R_{model\ C}}{R_{Manual/BS8110}}$$

The manual BS 8110 result is used as the principal reference for the tributary/cladding comparison. For the shell model, the purpose is not to assume that the manual result is 'correct' a priori, but to quantify and interpret the difference.

RESULTS

From the results shown in Table 3, it can be seen that a substantial change occurs in the generated output between coarse 4.0 m and 2.0 meshes, and this is followed by a progressively smaller changes as the mesh size is decreased. The envelope moment in span 1-2 decreases from 355.12 kN.m at 4.0 m to 282.96 kN.m at 2.0 m and later stabilises around 298 kN.m. However, the moment in span 2-3 changes drastically from16.25 kN·m to 124.03 kN·m between the first t wo meshes and later stabilizes near 7 kN·m. The interior support moment in the same vein increases from 240.44 kN·m to 322.04 kN·m and then approaches 364 kN.m. These trends highlight that the coarser mesh does not adequately provide a stable idealisation of the shell response.

At the adopted 0.25 m mesh size, the change relative to the previously used 0.50 m mesh is 0.84% for the span 1–2 moment and 0.57% for the support-2 moment. Refinement from 0.25 m to 0.125 m changes these quantities by only 0.10% and 0.13%, respectively. 0.25 m is taken as the mesh size for convergence because refinement of the mesh size does not produce any substantial improvement in the member and nodal responses. Figure 6 summarises the result presented in Table 3. This convergence behaviour is in line with the methodology recommended by Słota and Wosatko (2025), who buttressed that independent verification of finite element program should be performed by the design engineer. They worked on the solution convergence and beam-plate interaction.

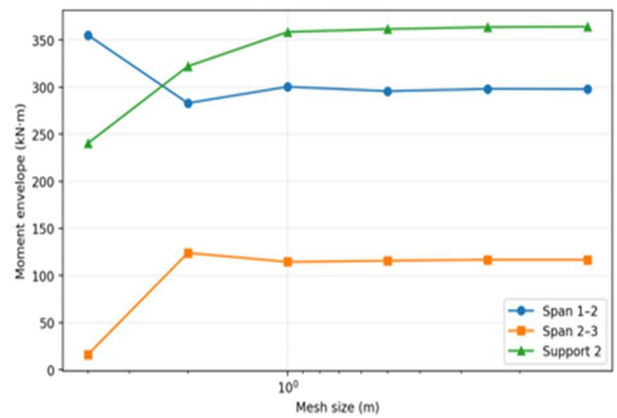

Figure 6: A graph of moment against mesh size

Table 4 shows that mesh refinement has a very much stronger effect on the memory and disk than the solver time for the first five mesh sizes. Memory use has a very sharp rise from 168,992 byte at 4.0 m to 4,108,952 bytes at 0.25 m, an approximately 24.3-times increase. Disk space also rises drastically from 116,112 byte to 8,469,552 bytes, an approximately 72.9-times increase. The calculation time increases from 1 to 4 seconds.

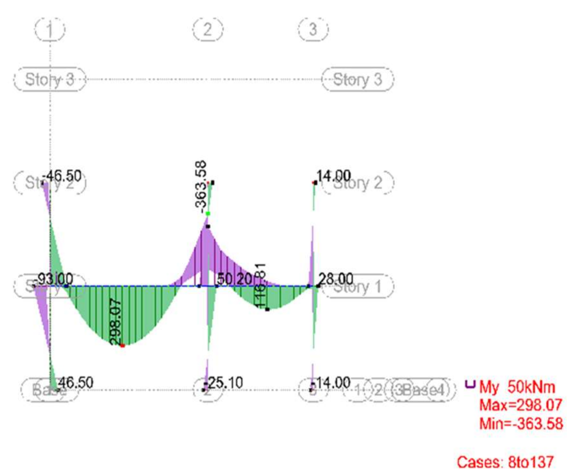

Figure 7: Subframe Bending Moment Envelope for Model S at 0.25 m mesh size

The bending moments envelope for Model S subframe and Model C subframe are shown in Figure 7 and Figure 8

Table 3: Mesh Convergence

S/N	Mesh size (m x m)	Envelope of Span Moment 1-2 (kN.m)	Envelope of Span Moment 2-3 (kN.m)	Maximum Support 2 Moment (kN.m)	Convergence based on support 2 moment (%)	Convergence based on span 1-2 moment (%)
1	4x4	355.12	16.25	240.44		
2	2 x 2	282.96	124.03	322.04	25.33846727	-25.50183772
3	1 x 1	300.32	114.47	358.48	10.16514171	5.780500799
4	0.5 x 0.5	295.59	115.7	361.53	0.843636766	-1.600189452
5	0.25 x 0.25	298.06	116.80	363.58	0.563837395	0.82869221
6	0.125 x 0.125	297.76	116.71	364.05	0.129103145	-0.100752284

Table 4: Computational Cost

S/N	Mesh size (m x m)	Time (seconds)	RSAP Memeory Use (B)	Disk Space (B)
1	4x4	1	168992	116112
2	2 x 2	1	265624	295872
3	1 x 1	1	413480	611184
4	0.5 x 0.5	1	1394832	2209200
5	0.25 x 0.25	1	4108952	8469552
6	0.125 x 0.125	4	16155720	33247536

Table 5: Two- Span Continuous Beam Bending Moment Envelope

Response location	Manual (kN·m)	Model C (kN·m)	Model S (kN·m)	C error (%)	S error (%)	C ratio	S ratio
Span 1–2	365.69	375.77	298.07	2.76	-18.49	1.028	0.815
Span 2–3	163.57	158.22	116.8	-3.27	-28.59	0.967	0.714
Support 2	505.12	504.64	363.58	-0.10	-28.02	0.999	0.720

Table 6: Column response

Column response	Manual	Model C	Model S	C vs manual (%)	S vs manual (%)
Axial load (kN)	2280	2667.94	2805.77	17.01	23.06
Top moment (kN·m)	60.41	60.34	50.2	-0.12	-16.90

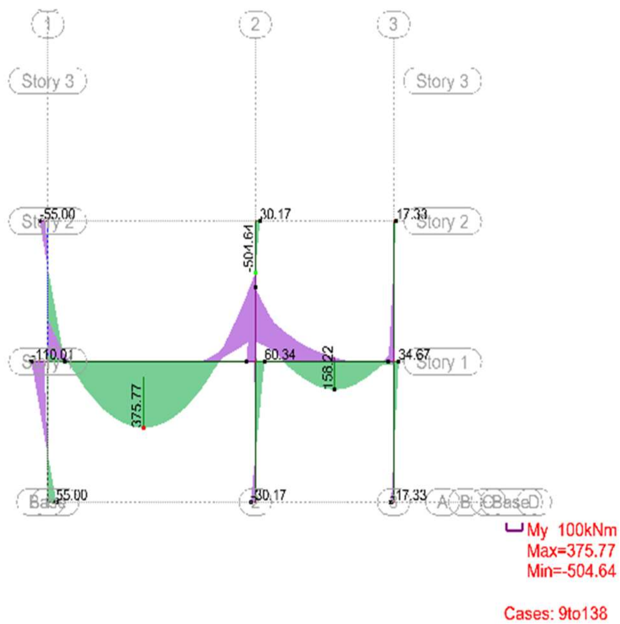

Figure 8: Subframe Bending Moment Envelope for Model C

respectively. The values of the response envelopes presented in Table 5 are extracted from Forces and Table Columns of RSA.

The two-span continuous beam 1-2-3 produces different bending moment envelope from the manual and the computer models. Model C subframe has no finite element mesh since it is made up of cladding object while Model S subframe is meshed at 0.25 m shell size. The manual envelope obtained separately using Hardy Cross moment distribution in an excel sheet gives a maximum value of 365.69 kN·m, the cladding value and the shell value is 365.69 kN·m, 298.07 kN·m (-18.49%). However, for span 2-3, the corresponding values are163.57 kN.m, 158.22 kN.m and 116.80 kN·m, giving a cladding and shell difference of -3.27% and -28.59% respectively. At interior support 2, the manual, cladding and shell models response values are 505.12 kN·m, 504.64 kN·m and 363.58 kN·m, respectively. The cladding differs by only -0.10%, whereas the shell is -28.02% below the manual reference.

The major finding of this study is the consistency of Model C subframe with the manual analysis and the systematic reduction of Model subframe relative to both. The cladding-to-manual ratios are 1.028, 0.967 and 0.999, respectively, showing close agreement. However, the shell-to-manual ratios are 0.815, 0.714 and 0.720. Thus, the shell predicts 18.5% lower span 1-2 moment and about 28% lower span 2-3 and support 2. This is not indicative of the fact that the shell model is erroneous; it rather highlights that the two structural idealisations have different load transfer mechanism.

From Table 6, it can be shown that interior-column supporting the two-span continuous beam has a different pattern from the beam moment. For obtaining column axial load, Model S and Model C are fully analysed with all the generated 138 live load patterns. The manual axial load obtained using tributary one-way loading is 2280 kN, whereas Model C and Model S produce 2667.94 kN and 2805.77 kN respectively. With reference to the manual result, these are increases of 17.01% and 23.06%, respectively. This shows that unlike the moment envelopes, the shell model attracts more axial load to the interior column under study.

For the same interior column under study, moment at the top of the ground-to-first floor from the manual analysis is 60.41 kN.m, Model C and Model S have moments of 60.34 kN.m and 50.20 kN·m respectively. Model C differs with the manual output by only 0.12%, while Model S is approximately 16.90 % lower than the manual value.

DISCUSSION

Interpretation of the beam-envelope difference

From the responses presented, the most important result is the close agreement between the manual BS 8110 subframe calculation and Model C subframe, contrasted with the substantially lower shell moments. This trend is mechanically not far-fetched since a tributary or cladding idealisation transfers surface loads to supporting frames without representing the slab as a stiff structural plate in the same way a shell element does. Conversely, the shell idealisation of slab in RSAP allows it to share load through flexure because the relative stiffness of structural components is considered Pechorskaya et al. (2021) reported that in RSAP finite element meshing, the relative stiffness of the structural components is considered and further noted that a concrete slab idealized by shell elements has out-of-plane stiffness and participate in load carrying through slab flexure.

Relationship to live-load patterning

Yadav and Garg (2017) demonstrated that five-bay by five-bay frame under pattern load produced greater beam bending moment that under conventional all-span gravity loading. They also reported that the effect was more pronounced for bending moment than beam shear or axial load.

The present study similarly targets an interior continuous subframe, making the BS 8110-patterned manual envelope an appropriate reference for critical gravity-load response.

Column response and redistribution

The internal column results serve as a useful evidence that the shell model is simply reducing all the structural loads. While the continuous beam bending moment envelope due to shell idealisation (subframe of Model S) give higher output, the interior-column axial load is greater that both the manual and Model C values. This is in harmony with the redistribution of gravity load through the floor/frame system. This is a response pattern and not a proof of any particular mechanism.

Numerical reliability and mesh adequacy

The convergence results substantially strengthen the interpretation of the shell response. The 0.25 m solution is already stable relative to the 0.50 m mesh, and the 0.125 m refinement changes the governing support and span moments by less than 0.13%. This indicates that the approximately 28% difference between shell and manual/cladding support moment is far larger than the residual mesh change between the two finest meshes. The difference is therefore unlikely to be explained by insufficient mesh refinement alone, although other FE modelling assumptions remain to be isolated.

CONCLUSIONS

1) The shell finite-element model reaches a practically stable solution at a 0.25 m mesh. Refinement to 0.125 m changes the reported support-2 moment by only 0.13% and the span 1–2 moment by about 0.10%, confirming that the principal shell response is numerically converged at 0.25 m.
2) The cladding model reproduces the manual beam-envelope results closely: the largest absolute difference among the three reported beam responses is 5.35%, while the interior support moment differs by only 0.48%.
3) The shell model produces systematically lower beam moments than the manual and cladding models, with reductions of approximately 18.5%

for span 1–2 and 28% for span 2–3 and the interior support.

4) The shell model does not reduce all structural actions. The investigated interior-column axial load increases from 2280 kN in the manual analysis to 2805.77 kN in the shell model, while the column top moment decreases from 60.41 to 50.20 kN·m. This indicates that there is likely redistribution of structural actions rather than a uniform reduction.
5) The approximately 28% shell reduction in the interior support moment is much larger than the residual change produced by the final mesh refinement. The difference is therefore unlikely to be caused solely by mesh density.
6) The results demonstrate why manual and RSAP results should not be treated as automatically equivalent when different floor idealisations are used. The load arrangement may be identical while the structural load-transfer mechanism is different.
7) The reliability of computer-based structural analysis should not be judged solely by the sophistication of the software employed, but by the appropriateness of the structural idealisation, the quality of the input assumptions, the adequacy of verification procedures, and the professional judgement applied in interpreting the results.

RECOMMENDATION

I. Investigation into the response of subframes incorporating simplified one-way shell-element slab models subjected to span-to-span live loading, to facilitate a comprehensive comparison with the response envelopes obtained from the manual and cladding idealisations.

II. Repeat the manual analysis by considering other subframe idealisations and live load arrangements described in BS 8110 or any other design code such as EC2 or ACI 318. The simplified manual analysis should then be compared with cladding and shell models having similar dead and live loads arrangement; proper generalization if any, can then made.

III. The manual analysis to any particular code should be used as reference for tributary/cladding model. It should not be assumed that the shell model must produce the same moments; the results differences are then interpreted as a modelling-response question.

IV. The reliability of computer-based structural analysis should not be judged solely by the sophistication of the software employed, but by the appropriateness of the structural idealisation, the quality of the input assumptions, the adequacy of verification procedures, and the professional judgement applied in interpreting the results.

Limitations

In this study, only an interior reinforced concrete subframe consisting of two-span continuous beams supported by ground to first floor columns and first to second floor columns is considered. This was done in order to simplify comparison with the manual analysis. All the columns used in the subframe analysis are assumed to be fixed both in the manual and the computer models.

Further, Model S is analytical finite element in which the program generates meshes and distribute the applied loads through the element model. In this study, simplified one-way and two-way shell elements are not considered. Hence, the shell element does not distribute the applied loading as rectangular, trapezoidal or triangular.

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