Behaviour of Seven-Storey Reinforced Concrete Frames with Infill and Interfaces Under Static Load

A. Selvakumar, V. Thirumurugan, and K. S. Satyanarayanan

1 Introduction

Modern construction techniques and advanced equipment are simplifying the construction practise. Reinforced concrete (RC) is primarily used in the construction industry for building the structures. The development of high-rise buildings is becoming a symbol of urbanization in an area. In these urbanizing and urbanized areas, high-rise buildings are more to manage the space. The problems associated with these buildings are also common. In small structures, the effects of imposed loads are ignored because of their null impact or slight impact in the structures. But, in tall buildings, the impacts due to imposed loads are unavoidable, since they are giving drastic damage to the structures based on the intensity of imposed loads. Bricks are most commonly used as non-structural infill material which increase the strength and stiffness of the frame. Understanding the behaviour of infill in such structures is essential for the structural engineers to nullify or minimize the drastic damages due to impact loads. Masonry work in a structure is mainly for partitioning the space. But they absorb and dissipate the energy due to loading actions. This case changed the structurally determined failure modes and it is due to the interactions between the infill and RC elements.

The effects of masonry infill in an RC frame are positive in some cases and cause drastic damage to the structure in many cases. Kaplan and Sarah say the effects of non-structural infill elements are considered in earthquake regulations of many

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countries (Algeria, Colombia, Costa Rica, the European Union, France, Israel, the Philippines, etc.) [1]. A vast research has been done to study the frame and infill interaction effects in recent decades used tie bars as a connector for rigid frame–infill interaction [2–7]. From the study, it is suggested that frame–infill interaction due to uneven arrangement of infill walls may create torsional damage or soft storey effect which is harmful in seismic response [8–10].

It is mentioned that static monotonic and reverse cyclic loading tests are conducted by many authors on un-reinforced masonry models [11–15]. It is proposed to avoid the brittle failure of masonry infill in a structure with masonry work 'strong frame-weak infill' method [16, 17]. The isolators or the flexible element between infill and frame is found to be effective to reduce the frame–infill interaction and leaving gap between frame and infill is also found to be effective. The failures in infill are reduced considerably by different interface materials or providing frame–infill gap was reported in the study [1, 18–23]. The effective stiffness of the model is slightly greater for reverse cyclic loading than monotonic loading. The test results obtained vary with the loading mechanism, material properties, size of the specimen, scale of the model, aspect ratio of the frame, etc. [24]. The loading arrangement differs based on the application of model and with the above-mentioned parameters [25]. Authors have done different types of loading arrangements and tests in which loads are applied in laboratory tests rather different for real-time seismic loads [15, 26, 27]. An adoptive interface investigation study revealed that the RC frame with masonry infill and pneumatic interface is found better for energy absorption and dissipation. Experimental and analytical study of single-bay seven-storey RC frames are studied for different interfaces and varying interface pressures in pneumatic interface [28–30].

2 Finite Element Modelling of the Frame

A seven-storey finite element model is designed for the proposed design specifications using finite element modelling software Abaqus. Three different types of RC frames are modelled and analysed to study the performance. The frames modelled and analysed are RC bare frame (BF), infill frame with cement mortar interface (IFCMI) and infill frame with pneumatic interface (IFPI). BF, infill frame with interface and reinforcement in frames are shown in Figs. 1, 2 and 3, respectively. The dimensions and the reinforcement details of the model are given in Tables 1 and 2. Each element in the models is meshed into finite elements based on optimization study. For the interaction between interface with infill and RC frame, tie connection is provided. Embedded interaction is assumed between concrete and reinforcement. The cover of 10 mm is provided in the model. Boundary condition is considered as fixed boundary and 150 mm of projection of the beam is designed at the loading floors for the convenience of loading in experimental investigations. The conventional (cement mortar) interface and non-conventional interface (pneumatic interface) are designed as solid element and pressure elements.

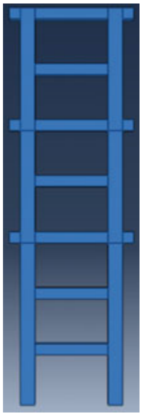

Fig. 1 BF in ABAQUS

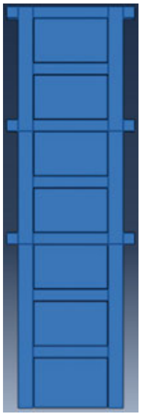

Fig. 2 Infill frame with interface

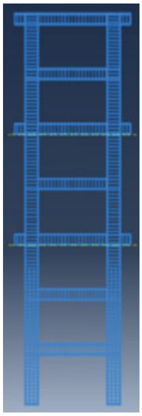

Fig. 3 Reinforcement in models

Table 1 Details of elements

S. no.	Element	Dimensions in (mm)	Specifications (mm)
1	Beam	1000 (clear span)	150 × 100 (cross section)
2	Column (ground storey)	675 (clear height)	200 × 100 (cross section)
	Column (all other storeys)	600 (clear height)	
3	Infill (ground storey)	980 × 655	100 (depth)
	Infill (all other storeys)	980 × 580	
4	Interface (ground storey)	1000 × 675	10 (thickness)
	Interface (all other storeys)	1000 × 600	

Table 2 Reinforcement details

S. no.	Element		Description
1	Beam	Main bar	4 Nos of 10 mm dia. bars
		Stirrups	6 mm dia. 2-legged stirrups @ 50 mm c/c
2	Column	Main bar	12 Nos of 10 mm dia. bars
		Stirrups	6 mm dia. 2-legged stirrups @ 50 mm c/c

3 Analysis Procedure

The seven-storey models are analysed in finite element modelling software Abaqus 6.14. Elements of the frame models are created as different parts. Material properties are assigned to each part. The complete frame model is done by assembling the parts together. Elements are meshed based on their size and optimization study (Figs. 4 and 5). The single-bay seven-storey model is fixed at the base of the two columns.

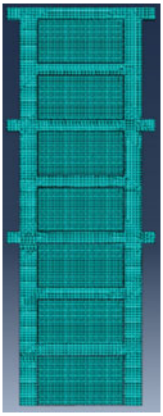

Fig. 4 Elements meshed for analysis

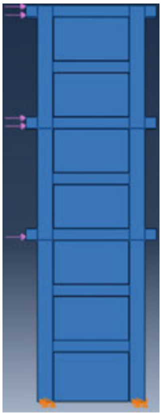

Fig. 5 Boundary condition and loads

Total lateral load of 90 kN (each 30 kN load at 3rd, 5th and 7th storeys) is applied to the frame model. Load is applied as equivalent pressure force of 2 N/mm^2 (for the cross section of beam 100 mm × 150 mm).

4 Results and Discussions

Three models are analysed in this study. From the analysis, output parameters of BF, IFCMI and IFPI are compared. Parameters like von Mises stress, maximum and minimum principal stress and displacements are compared.

4.1 Principal Stress

Principal stress is the maximum normal stress acts on the structure from which the performance of the material can be examined based on the allowable criteria. The maximum and minimum principal stress values of each storey are compared for IFCMI and IFPI. Distribution of the maximum and minimum principal stresses of the RC frame with infill and interface are shown in Figs. 6, 7, 8 and 9. Comparison of the stresses shown in Figs. 10 and 11. It is clear from the images that maximum principal stress is higher till the third storey for IFCMI than IFPI and, from there on, it is almost equal for both. Similarly, the minimum principal stress is lower till the fifth storey for IFCMI than IFPI and, from there on, it is almost equal for both.

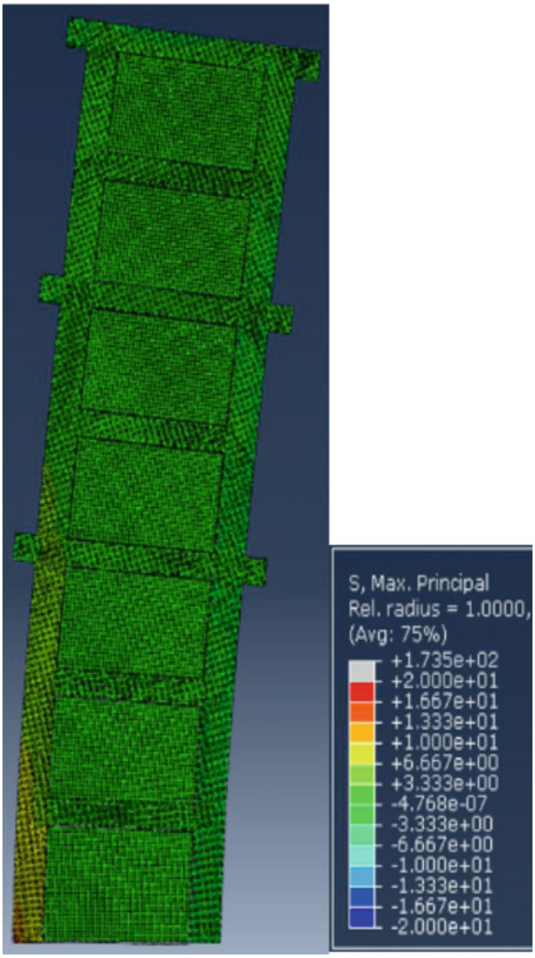

Fig. 6 Maximum principal stress—IFCMI

4.2 Displacement

The maximum displacements at each storey for all the three frames are taken from the analytical results. Comparisons of the displacements of all the three frames are shown in Fig. 15. In this, BF is displaced to the maximum of 27.44 mm, IFPI is displaced to 11.31 mm and IFCMI and displaced to 6.07 mm at top storey. Displacements of the different storeys of all the three frame models are shown in Figs. 12, 13 and 14. The minimum deflections at the first storey of the frames found as 2.73 mm for BF, 0.44 mm for IFCMI and 1.08 mm for IFPI.

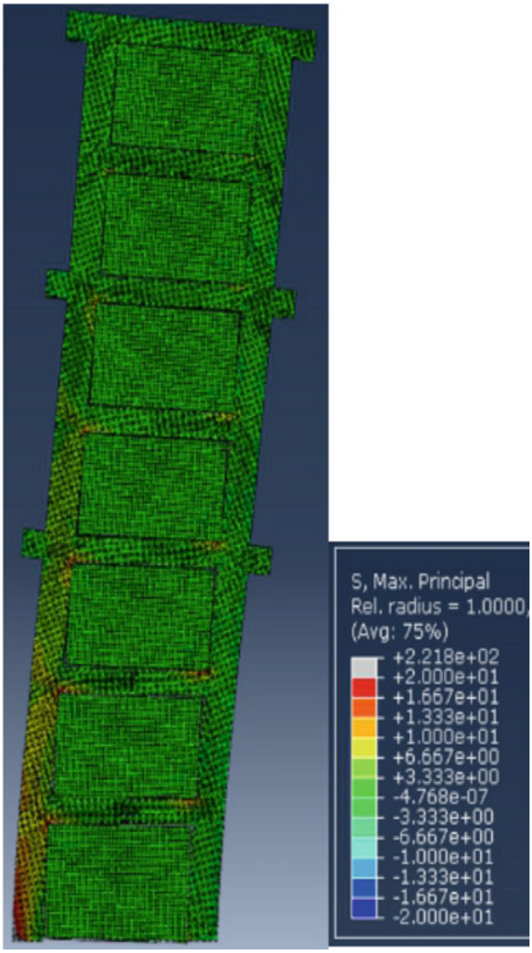

Fig. 7 Maximum principal stress—IFPI

4.3 Von Mises Stress

The yield of a material can be predicted under different loading conditions using von Mises stresses. Von Mises stress distributions of the BF, IFCMI and IFPI are shown in Figs. 16, 17 and 18. From the figure, it is clear that von mises stress is higher for BF and lower for IFCMI than the others.

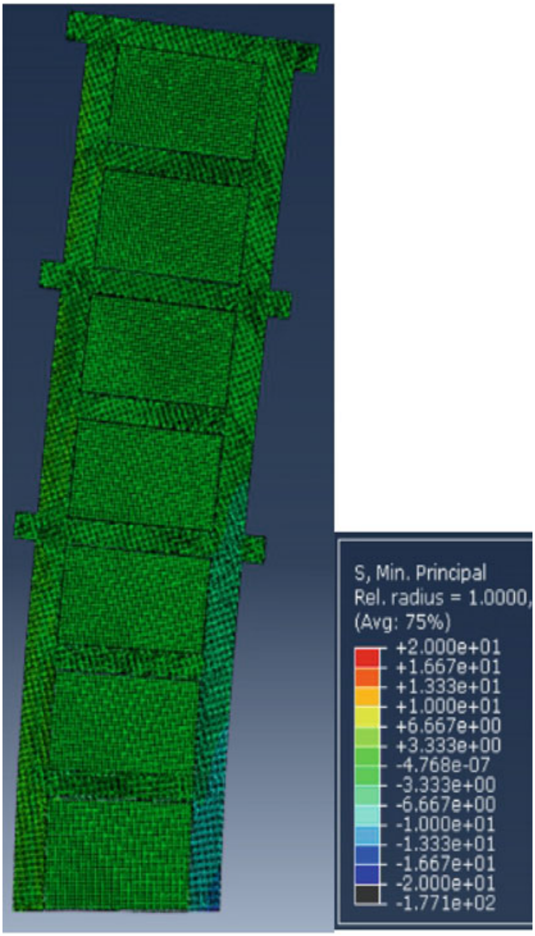

Fig. 8 Minimum principal stress—IFCMI

5 Conclusion

The following conclusions are given based on the analysis of the single-bay seven-storey RC frame.

1. The presence of interface and the types of interface are altering the principal stresses.
2. Maximum principal stress of IFCMI is more than that of IFPI up to third storey, and after that, it is comparatively equal for rest of the stories.
3. Minimum principal stress is more for IFPI than IFCMI up to fifth storey, and after that, it is approximately equal.

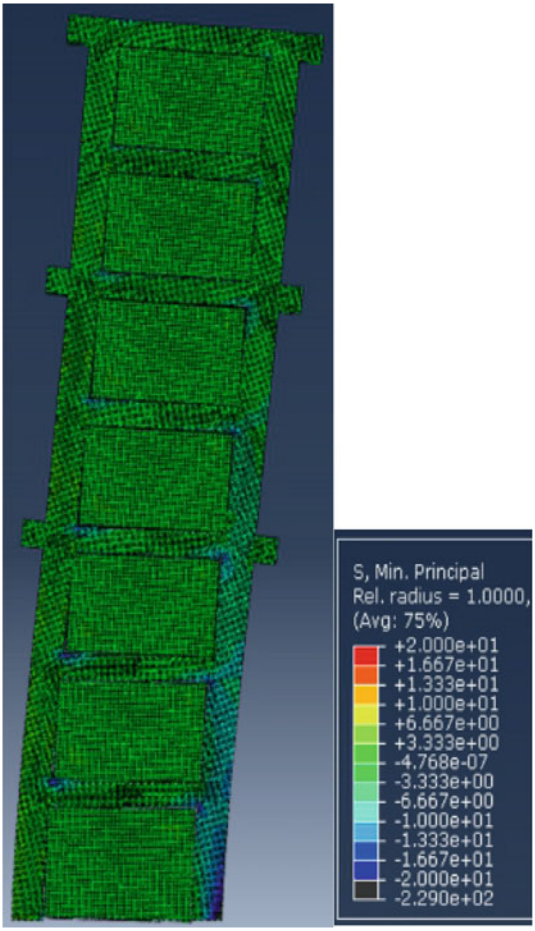

Fig. 9 Minimum principal stress—IFPI

4. BF is displaced to larger extent than IFCMI and IFPI.
5. The maximum displacement of BF is 27.44 mm. IFPI and IFCMI are displaced 0.41 times and 0.22 times of BF.
6. Von Mises stress is more at beam column joints of BF than IFCMI and IFPI.

From the results of the analysis, it is clear that infill frames are good in strength and load-carrying capacity. The infills and interfaces are playing vital role in the stability of structure, load-carrying and load distribution mechanisms as well as changes in structural parameters.

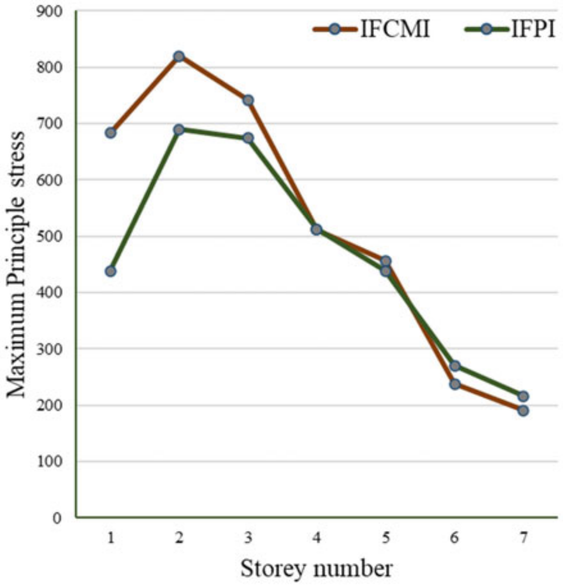

Fig. 10 Comparison of maximum principal stresses

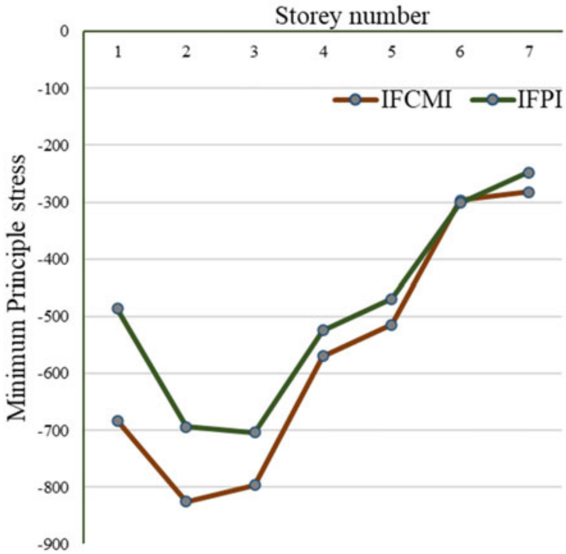

Fig. 11 Comparison of minimum principal stresses

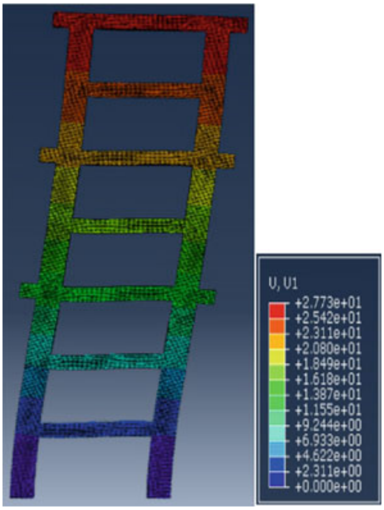

Fig. 12 Deflection of BF

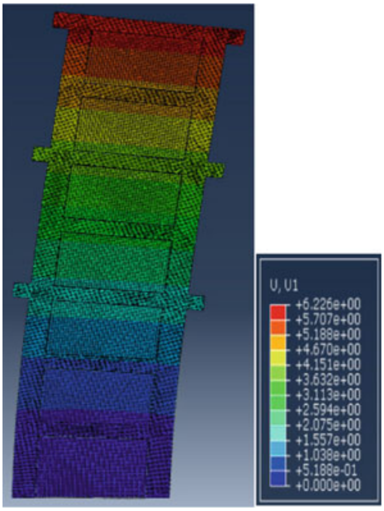

Fig. 13 Deflection of IFCMI

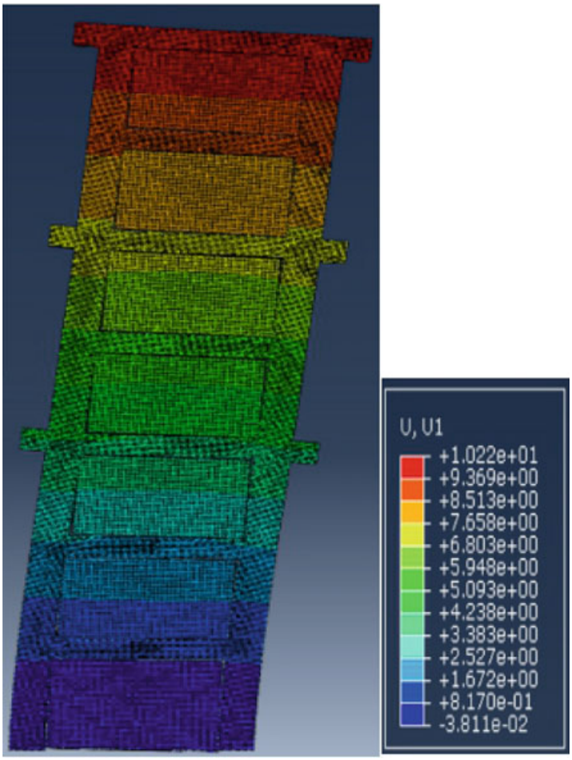

Fig. 14 Deflection of IFPI

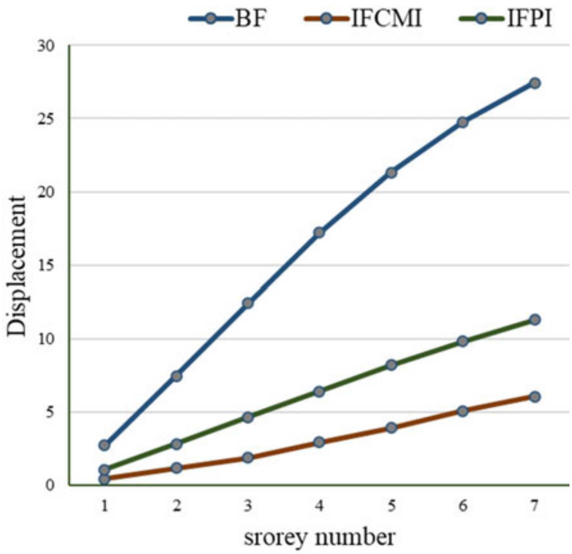

Fig. 15 Deflections of BF, IFCMI and IFPI

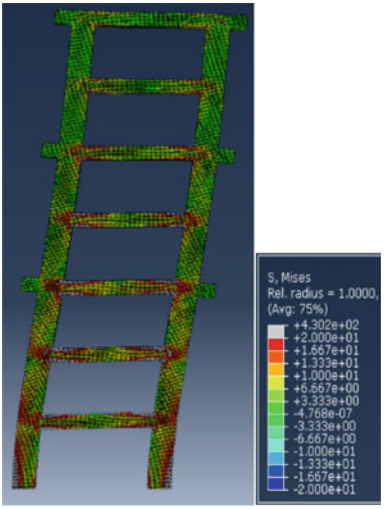

Fig. 16 Von Mises stress in BF

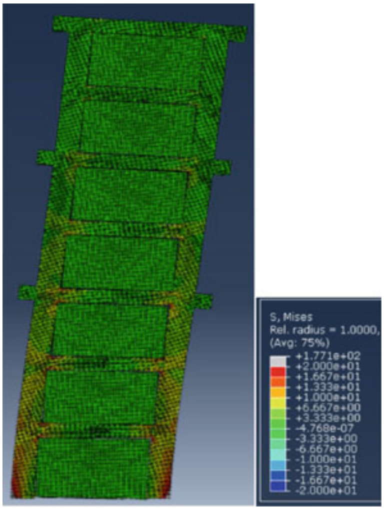

Fig. 17 Von Mises stress in IFCMI

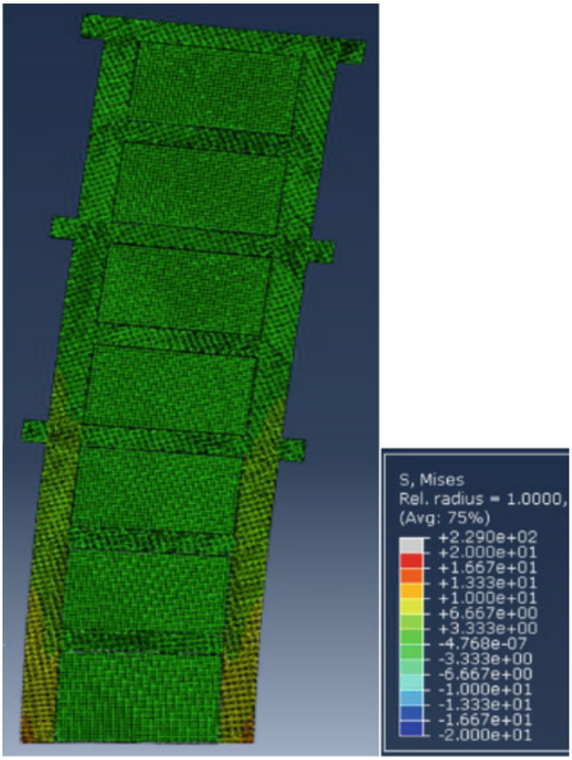

Fig. 18 Von Mises stress in IFPI

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