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Comparative Study of a R.C.C Structure for the Elimination of Expansion Joint Subjected to Temperature Stresses

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ABSTRACT
This comparative study focuses on the behavior of a mid-rise long building in the presence and absence of an expansion joint under seismic, wind and temperature loading using Staad Pro software. In this study 2 models are subjected to different load cases involving gravitational loads, temperature loads, seismic and wind loads in the presence and absence of expansion joint and the parameters like displacements, drifts, bending moments and steel consumption were evaluated. From the study it was observed that both the Models showed considerably lesser values of parameters like Steel consumption, Maximum Bending Moments, Storey drift and Average displacements in the presence of an expansion joint. Based on the overall output is can be suggested that the elimination of the expansion joint should be considered only for Model A because in case of Model B the structure was seen to become very uneconomical with increased values of the parameters compared under higher seismic zones.
Keywords – Seismic Analysis, Expansion joints, Temperature stresses

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I. INTRODUCTION

An expansion joint may be defined as a mid-structure separation designed to relieve stress on a building material which are experienced during the life span of the structure. The expansion of the structure depends upon numerous factors like architectural aspects of the structure, temperature changes, provision for temperature control, materials of construction etc. Expansion joints are necessary in a structure as they counter the adverse effects a structure experiences during its lifespan due to temperature variations [1-3]. This study can be helpful in Civil Engineering as it gives a clear picture of the changes a structure undergoes when subjected to temperature loading and also its variation under different seismic zones.

II. LITERATURE REVIEW

Michael J Pfeiffer and David Darwin (1987) in their report gave a brief description of the process involved in working out an expansion joint in buildings, the purpose of each type of joint and its selection based on requirement [4]. René de Borst and Paul P.J.M. Peeters (1989) developed an algorithm by simultaneously considering the effect of thermal dilatation, changes in elastic properties with increasing temperatures, and the calculations were carried out with the DIANA finite element code [5]. James M Fisher (2005) studied and examined different structures with his focus basically on the provision of expansion joint and the basic guidelines used to determine the requirement of an expansion joint at any given location and also on the requirements of the expansion joints pertaining to commercial and industrial structures [6]. It also includes some of the basic formulae to be used for determining the general information regarding expansion joints in structures. Matthew D Brady (2011) had discussed the guidelines for dealing with dimensional changes in building structures under the effect of changing temperatures [7]. It also includes the additional details regarding the need, location, type, codal requirements and recommendations of expansion joints. B. Dinesh Kumar and K. Vidhya (2014) presented a study involving the analysis of a G+1 RCC structure without an expansion joint and difference in floor heights for its behavior under different loadings [8]. The comparisons of column rebar and support reactions were done and were observed to be almost similar in both the cases. Previous studies done on similar topics involve work done on expansion joints or temperature loading alone and also how the behavior changes under different seismic zones. A combined effect of these two parameters is hardly available and also does not portray a clear image of the complications faced in terms of changes in the structural behavior or the different load combination involved in accomplishing the task successfully. An attempt has been made in this study to get a more realistic approach for the situations where an elimination of expansion joint is preferred.

III. ANALYTICAL MODELS

The present work aims for the analysis of two different models, i.e. Model A and Model B with varying dimensions and also the magnitude of loading under 2 different cases as follows:

Model A:

Case 1: Where the structure is taken as a complete single unit without the presence of an expansion joint subjected to seismic, wind and temperature loading.

Case 2: Where the structure is divided by introducing two expansion joints in the structure as per the condition in I.S codes. The first expansion joint is placed along the width of the structure at a distance of 30m from the origin along X axis whereas the second expansion joint is placed along the length of the structure at a distance of 40m from the origin along Y axis.

In case of Model A, the structure is assumed to be located in zone II and the loadings are done accordingly as per IS 1893 (Part 1) Criteria for earthquake resistant design of structures [9].

The temperature variation is taken as 32°C which is the difference of the maximum (43°C) and minimum (11°C) temperature as per the environmental data services of the city. The three dimensional view of Model A is shown in Figure 1. The dimensions and other detailed information of the models are given in Tables 1 and 2.

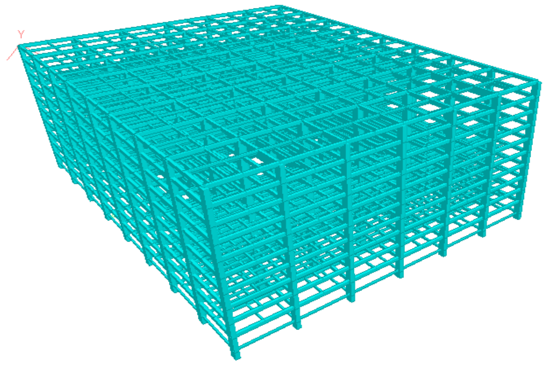

Figure 1: Three Dimensional view of Model A.

Table 1: Preliminary data considered for the analysis

S. No	Variable	MODEL A	MODEL B
1.	Plan dimensions	60m X 80m	60m X 120m
2.	Number of Stories	10	
3.	Floor height	3 m	
4.	Total height of Building	30m	
5.	Size of Columns	1.06x1.06m (for inner columns) 0.9x0.9m (for outer columns)	1.21x1.21m (for inner columns) 1.06x1.06m (for outer columns)
6.	Size of Beams	0.45 X 0.53m (Outer beams) 0.38 X 0.53m (Fixed beams) 0.23 X 0.30m (S.S beams)	0.45 X 0.60m (Outer beams) 0.38 X 0.68m (Fixed beams) 0.23 X 0.45m (S.S beams)
7.	Spacing between columns	10 meters	
8.	Depth of slab	125mm thick	

Table 2: Materials and Loading details of the building models

S. No	Property	Value
1.	Materials	Concrete (M30 and M20) and Reinforced with HYSD bars (Fe500)
2.	Specific weight of RCC	25 kN/m^3
3.	Live Load	5.0 kN/m^2
4.	Wall Loads	10.5kN/m and 2kN/m (parapet wall)

Model B:

Case 1: Where the structure is taken as a complete single unit without the presence of an expansion joint subjected to seismic, wind and temperature loading.

Case 2: Where the structure is divided by introducing three expansion joints in the structure as per the condition in I.S codes. The first expansion joint is placed along the width of the structure at a distance of 30m from the origin along X axis; the second expansion joint is placed along the length of the structure at a distance of 40m and the third one being placed at a distance of 80m from the origin along Y axis.

In case of Model B, the structure is assumed to be located in zone V and the loadings are done accordingly as per IS 1893 (Part 1) Criteria for earthquake resistant design of structures.

The temperature variation is taken as 32°C which is the difference of the maximum (43°C) and minimum (11°C) temperature as per the environmental data services of the city. The three dimensional view of Model B is shown in Figure 2.

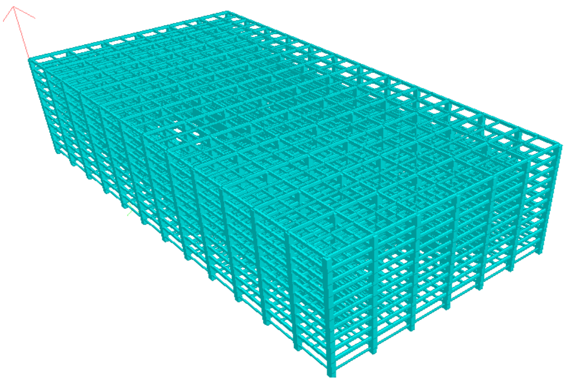

Figure 2: Three Dimensional view of Model B.

IV. RESULTS AND DISCUSSIONS

4.1 Model A Results

4.1.1 Storey Drifts and Average Displacements

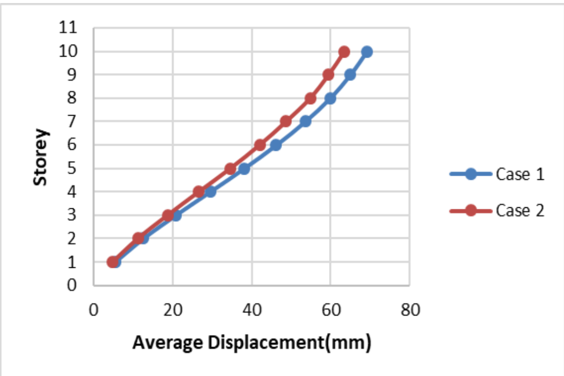

Figure 3: Comparison of Average Displacements of Model A

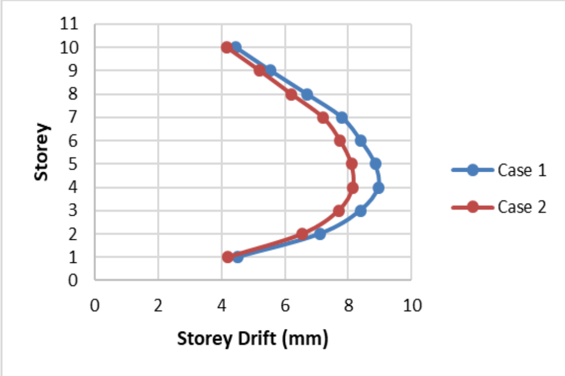

Figure 4: Comparison of Storey Drifts of Model A.

Storey drift can be defined as the displacement of one level relative to another level above or below it whereas average displacement is the displacement of one level with respect to the base of the structure. Both these values play a key role when the structure is designed for seismic loading.

The lesser these value are, the more stable the structure becomes. It can be observed that the presence of an expansion joint in the structure leads to reduction in the values of both storey drifts and average displacements by 10% hence making it more stable and durable. The above data is represented in Figures 3 and 4 respectively.

4.1.2 Steel Consumption

For comparison of column moments and steel consumption, the designed columns are divided into four groups as shown in Figure 5, viz., Group A consisting of columns with moment values from 300-400 kNm, Group B consisting of columns with moment values ranging from 400-500 kNm, Group C consisting of columns with moment values ranging from 500-600 kNm and Group D consisting of columns with moment values ranging from 600-700 kNm. For these column groups the area of steel is calculated and is depicted in Figure 6.

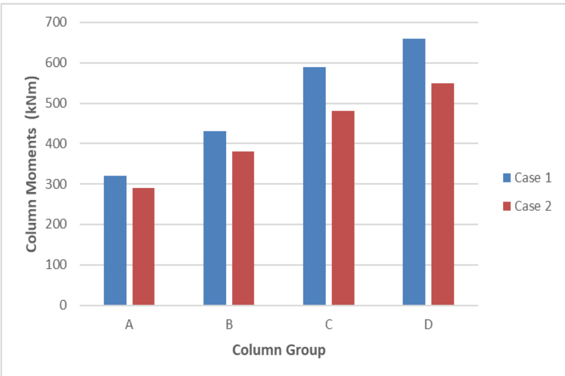

Figure 5: Comparison of Column Moments of Model A

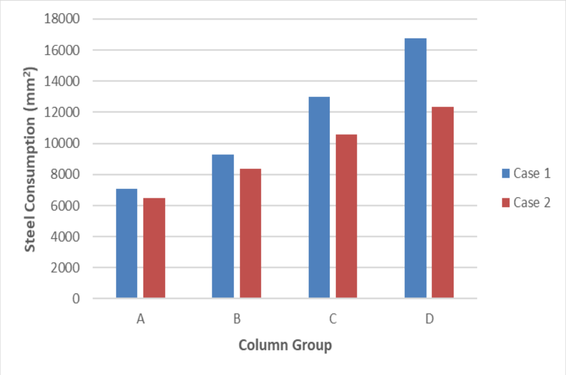

Figure 6: Comparison of Steel Consumption of Model A

It can be observed from Figure 5 that values of the moments developed are almost similar for 50% of the columns when compared in the presence and absence of the expansion joint. The values of the moments and loads developed being similar led to similar values of steel consumption as seen in Figure 6. For these columns the reduction in steel consumption is around 10% only.

Although the majority of the columns did show similar values, the remaining columns showed a considerable reduction in the values of steel consumption based on the difference in the moments and load values developed in these columns when an expansion joint was introduced. Hence, for these columns the reduction in steel consumption lies in the range of 15% - 20%.

The temperature loading applied in this case showed a minor effect when it comes to column reinforcement. The governing load cases observed were mostly a combination of gravity loads along with factor of safety. Only a few columns on the periphery were seen to have the governing load cases which involved temperature loads, but the change in values due to these loads was negligible when compared.

By observing this model, it can be said that the overall reduction in column reinforcement is around 20% when an expansion joint is introduced at suitable locations in the structure.

4.1.3 Comparison of Maximum Bending Moment in beams of bottom slab

The peripheral beams were divided into three groups as shown in Figure 7, namely, Group A consisting of beams with moment values ranging from 600-700 kNm, Group B consisting of beams with moment values ranging from 700-800 kNm, and Group C consisting of beams with moment values ranging from 800-900 kNm.

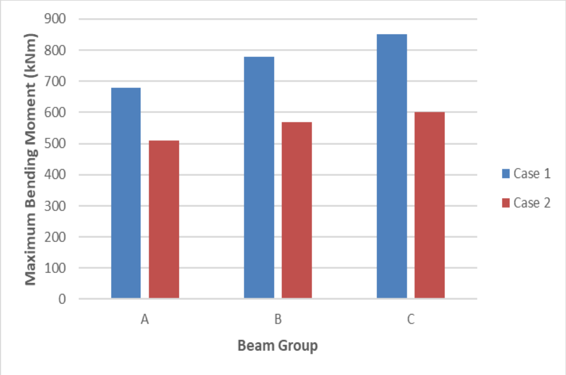

Figure 7: Comparison of Max Bending Moment in outer beams of bottom slab of Model A

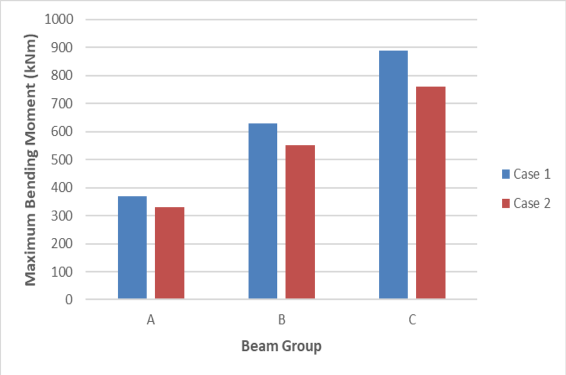

Figure 8: Comparison of Max Bending Moment in inner beams of bottom slab of Model A.

The inner beams were divided into three groups, namely, Group A consisting of beams with moment values ranging from 300-400 kNm, Group B consists of beams with moment values ranging from 600-700 kNm and Group C consists of beams with moment values ranging from 800-900 kNm as shown in Figure 8.

From the Figures 7 and 8 it can be seen that the maximum bending moments in the outer beams is reduced by 25% - 30% of its value when an expansion joint is introduced in the structure. The governing load case observed in these beams was the combination of seismic wind and temperature loads. However, the inner beams were not affected by the temperature loads, but an overall reduction in the moment values by 10%- 15% is observed when expansion joint is provided. It can be said that the introduction of an expansion joint leads to a reduction in the moment values which in turn makes the structure more economical and stable.

4.1.5 Comparison of Max Bending Moment in beams of Top slab

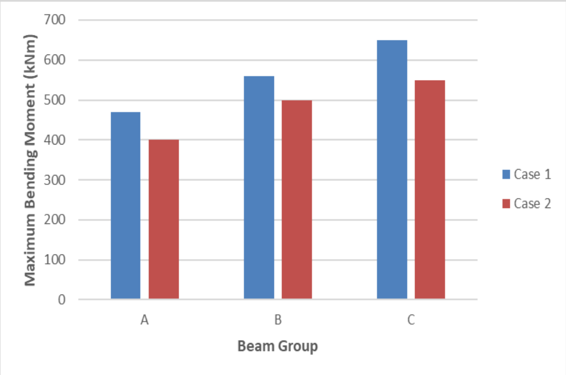

Figure 9: Comparison of Max Bending Moment in outer beams of Top Slab of Model A

The peripheral beams were divided into three groups for the purpose of design, namely, Group A consisting of beams with moment values ranging from 400-500 kNm, Group B consisting of beams with moment values ranging from 500-600 kNm and Group C consisting of beams with moment values ranging from 600-700 kNm as shown in Figure 9.

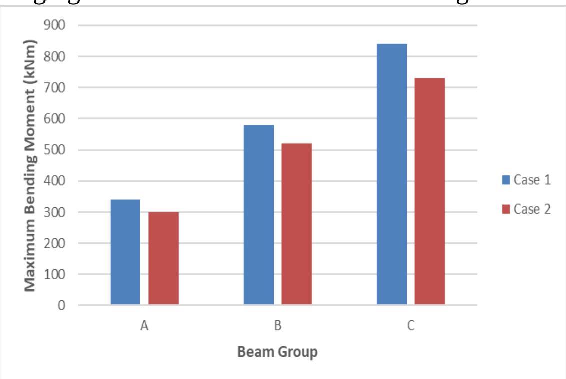

Figure 10: Comparison of Max Bending Moment in inner beams of Top Slab of Model A.

The inner beams were divided into three groups, namely, Group A consisting of beams with moment values ranging from 300-400 kNm, Group B consisting of beams with moment values ranging from 500-600 kNm and Group C consisting of beams with moment values ranging from 800-900 kNm as shown in Figure 10.

The temperature loading showed no effect in the beams of the top slab. The governing load cases in these beams have no trace of temperature load in them. However, by introducing an expansion joint in the structure, the maximum bending moments in the outer beams was reduced by almost 15% and for the inner beams the reduction is about 10% of its original value which were noted in the absence of the expansion joint.

4.1.7 Comparison of Support Reactions

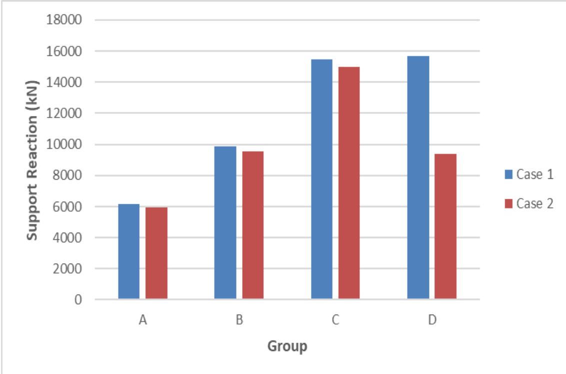

Figure 11: Comparison of Support Reactions of Model A

The support reactions resulting at the base were categorized into four groups as shown in Figure 11, namely, Group A comprising of columns with support reaction values ranging from 6000-6500 kN, Group B comprising of columns with support reaction values ranging from 9500-10000 kN, Group C comprising of columns with support reaction values ranging from 15000-15500 kN and Group D comprising of columns with support reaction values ranging from 15500-16000 kN.

It is seen that majority of the columns showed negligible or no change in the support reaction values in the presence and absence of an expansion joint. The reduction of support reaction values in these columns was around 5%. Only 20% of the entire columns which were located close to the point where an expansion joint was provided showed a considerable reduction in its value by almost 40%.

4.2 Model B Results

4.2.1 Comparison of Storey Drifts and Average Displacements

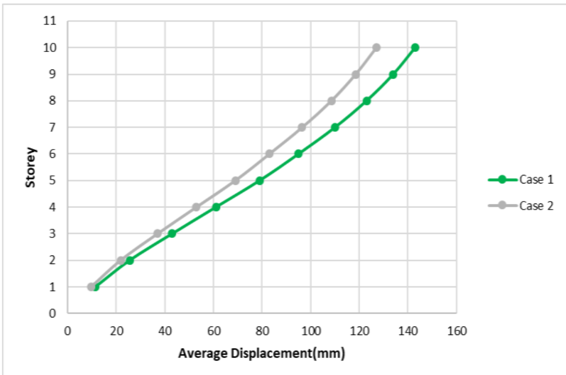

Figure 12: Comparison of Average Displacements of Model B

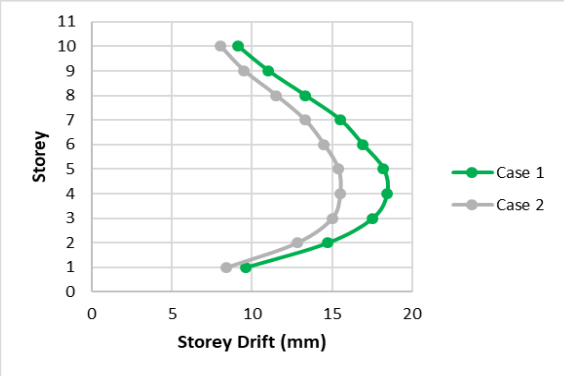

Figure 13: Comparison of Storey Drifts of Model B

For buildings which lie in higher seismic zones the storey drift and average displacements play a crucial role in the stability of the structure. A structural designer may design the structural elements based on the storey drift and displacement values obtained, but there are numerous other non-structural elements such as electrical and plumbing lines, etc., which have to be kept in mind as to how they may get affected under such deformations. Moreover, these non- structural elements have a different modulus of elasticity and behavior which needs to be taken into consideration as the damage to any such elements will have an adverse effect on the structure [10]. On the other hand, if the effect of P-Delta is taken into consideration, then situation becomes very critical since additional moments are developed whose value is equal to the load value (P) multiplied by the horizontal displacement of the element in consideration. These additional moments have an adverse effect on the structure if neglected and can also result in failure of the structure. Based on these points it can be said that the lesser the drift and displacement values, more stable the structure becomes and hence these values must be kept as low as possible.

From the Figures 12 and 13, it was observed that the presence of an expansion joint in the structure leads to a reduction in the values of both storey drifts and average displacements by 15% - 20% hence making it more stable and durable.

4.2.2 Comparison of Steel consumption

For comparison of column moments and steel consumption, the designed columns are divided into four groups depending on their moment values, viz., Group A consisting of columns with moment values of 500-600 kNm, Group B consisting of columns with moment values of 700-800 kNm, Group C consisting of columns with moment values of 800-900 kNm and Group D consisting of columns with moment values of 900-1000 kNm as shown in Figure 14. For these column groups the area of steel is calculated and is depicted in Figure 15.

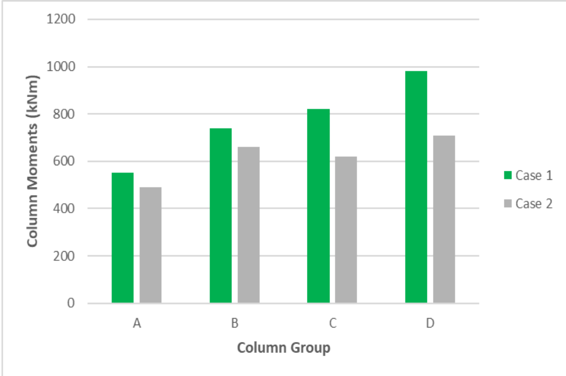

Figure 14: Comparison of Column Moments of Model B.

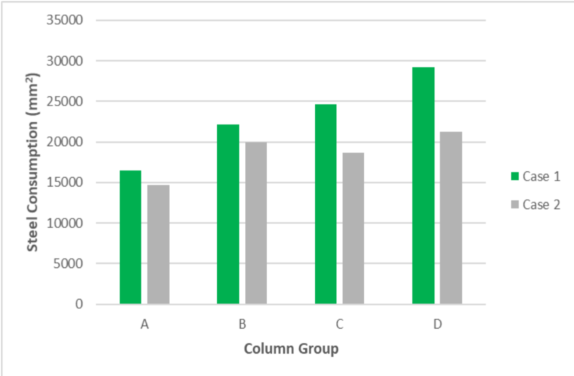

Figure 15: Comparison of Steel Consumption of Model B

It can be observed that the steel required values are very high as the structure is assumed to be in zone V and the loading is done accordingly. Only 20% of the columns have similar moment values in the presence and absence of expansion joint respectively. For the remaining 80% of the columns a considerable reduction in the moments and load values is observed when an expansion joint is introduced at suitable positions in the structure leading to a reduction in steel consumption 30% in these columns.

The temperature loading applied also showed its effect on the columns when the expansion joint is eliminated. In such a situation higher steel required values in certain columns are observed to be in the top storey and are governed by the load combination which included temperature load, unlike in case 2 where the same was required for columns in the lower storey. The advantage of this is that the columns in Case 2 can be subjected to column reduction unlike Case 1.

By observing this model, it can be said that the introduction of the expansion joint at suitable locations in the structure makes it very much economical in different aspects and also leads to an overall reduction in steel consumption value by 30%.

4.2.3 Comparison of Max Bending Moments in beams of bottom slab

The outer beams were divided into three groups as shown in Figure 16, consisting of Group A with moment values ranging from 800-900 kNm, Group B with moment values ranging from 900-1000 kNm and Group C with moment value ranging from 1100-1200 kNm.

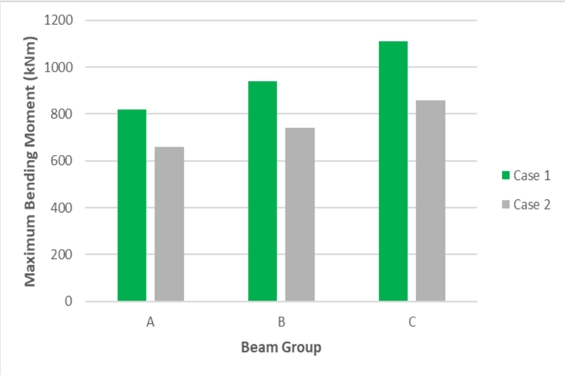

Figure 16: Comparison of Max Bending Moments in outer beams of bottom slab of Model B.

The inner beams were divided into three groups as shown in Figure 17 consisting of Group A with moment values ranging from 400-500 kNm, Group B with moment values ranging from 700-800 kNm and Group C with moment values ranging from 900-1000 kNm.

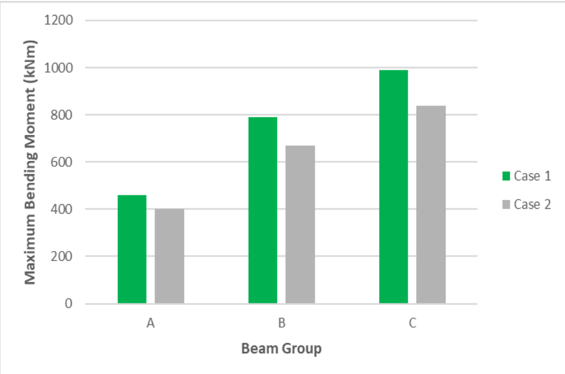

Figure 17: Comparison of Max Bending Moments in inner beams of bottom slab of Model B

From Figures 16 and 17, it can be seen that the maximum bending moments in the outer beams was reduced by almost 20% - 25% of the value which was noted down when the expansion joint was avoided. The governing load case observed in these beams was the combination of gravity, seismic wind and temperature loads. However, the inner beams were not affected by the temperature loads, but an overall reduction in the moment values by 20% was observed when expansion joint was provided in the structure.

4.2.4 Comparison of Max Bending Moments in beams of Top slab

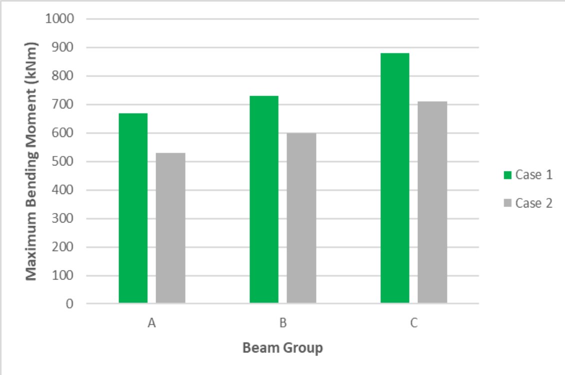

Figure 18: Comparison of Max Bending Moments in outer beams of Top Slab of Model B.

As shown in Figure 18, the outer beams were divided into three groups; namely, Group A with moment values ranging from 600-700 kNm, Group B with moment values ranging from 700-800 kNm and Group C with moment values ranging from 800-900 kNm.

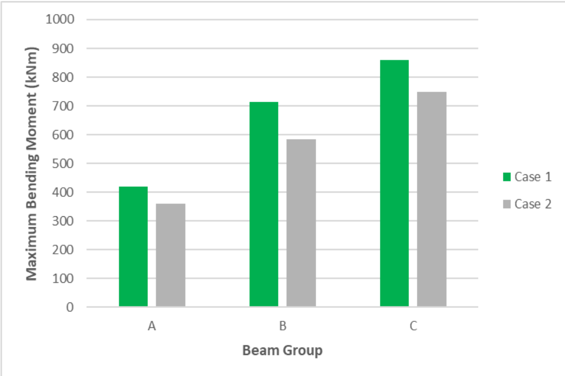

Figure 19: Comparison of Max Bending Moments in inner beams of Top Slab of Model B

As shown in Figure 19, the inner beams were divided into three groups; namely, Group A with moment values ranging from 400-500 kNm, Group B with moment values ranging from 700-800 kNm and Group C with moment values ranging from 800-900 kNm.

In Model B, the temperature loading showed its effect on both the outer as well as inner beams in the top slab. The governing load cases in these beams are a combination of gravity, earthquake, wind and temperature loads. When case 2 was implied on this model i.e. when an expansion joint was introduced in the structure the maximum bending moments values in the outer beams were reduced by20% and the inner beams were reduced by 18% of its value which were noted when the expansion joint was avoided.

4.2.7 Comparison of Support Reactions

The support reactions resulting at the base were categorized into four groups as shown in Figure 20; namely, Group A with SR values ranging from 7000-8000 kN, Group B with SR values ranging from 11000-12000 kN, Group C with SR values ranging from 16000-16500 kN and Group D with SR values ranging from 16500-17000 kN.

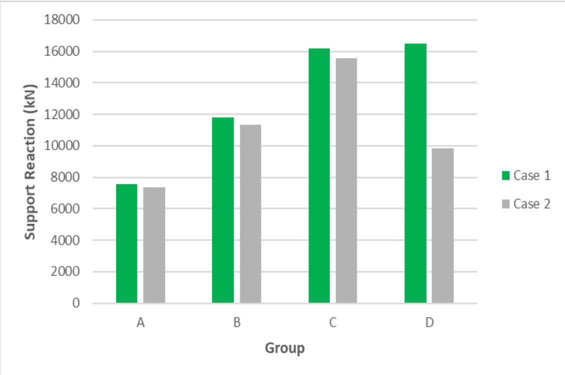

Figure 20: Comparison of Support Reaction of Model B

In case of Model B, majority of the columns showed considerable or no change in the support reaction values in the presence and absence of an expansion joint. The reduction in these columns is around 5% of the original value noted when the expansion joint is avoided.

Only 20% of the entire columns which were located close to the point where an expansion joint was provided showed a considerable reduction in its value by almost 40%.

4.3 Comparison of models from economy point of view

The most challenging part as a structural designer is not only to design a stable structure but also to maintain it as economical as possible while doing so, as the cost of construction of the structure is one such factor which lies directly in the hands of the structural designer.

The cost of construction in terms of steel quantity required in beams and columns is estimated for both Models under Case 1 and Case 2.

On observing the results of the study there is no denying the fact that provision of an expansion joint in the structure definitely contributes a lot in maintaining low cost of construction and vice versa. The tabular and graphical representation of the quantities and cost as per current rates in the market are given below in Table 3 and Figure 21.

Table 3: Comparison of Steel required and total cost Model A.

Case	Model A			Model B		
	Steel Required (Tonnes)	Cost per Tonne (Rupees)	Total cost (Cr)	Steel Required (Tonnes)	Cost per Tonne (Rupees)	Total cost (Cr)
1	2560	48500	12.41	5425	48500	26.31
2	2360	48500	11.44	4920	48500	23.86

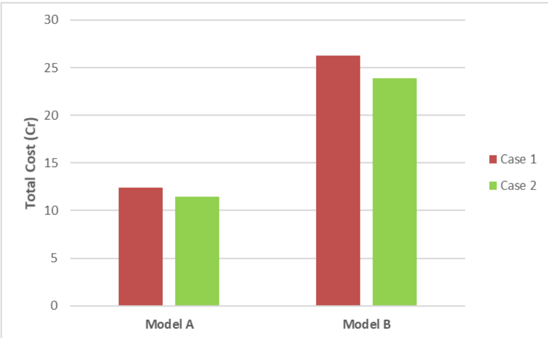

Figure 21: Comparison of Total cost of Steel required for Model A and Model B.

V. CONCLUSIONS

The results show that the presence of expansion joint results in a structure with lesser stresses and moments developed in its various elements which in-turn results in lesser sectional properties and steel consumption and hence leading to an economical design of the structure. Based on the results obtained from this study, the elimination of the expansion joint can be considered for Model A i.e. where the structure is not subjected to heavy loading, but the same is not recommended for Model B i.e. when the structure is subjected to heavy loading as it leads to a very complex and uneconomical design due to higher values of the different parameters associated with it. The above conclusion may not be the same for all the structures as the results vary for different structures based on various parameters. Therefore, a thorough investigation and observation has to be performed for any structure before considering the elimination of the expansion joint.

LIMITATIONS OF THE STUDY

The limitations of the study are as follows:

- The temperature loads are assigned to only those parts of the structure which are directly exposed to the sunlight.
- The temperature variation considered in the study was taken as the difference of daily maximum and minimum temperature.

RECOMMENDATION FOR FUTURE WORK

Further research can be carried out to study multistoried R.C.C structures subjected to temperature change due to internal heating i.e. factories with huge ovens and heaters placed inside the building, furthermore buildings with irregular geometry and the ones located on sloping ground can also be considered for the study. A comparative study can be done to study the response of the structure under different conditions. Cost comparisons under each case can also be done to find an economical solution.

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