

Thermal Analysis of Long Buildings for Elimination of Expansion joints

Department of Civil Engineering, Datta Meghe College of Engineering,
Airoli, Navi Mumbai 400708

ABSTRACT

In view of demanding architecture and present Industrial trend, long structures without any expansion joint is becoming a necessity of the project. As per Indian Standard code, IS-456:2000, buildings longer than 45m shall be analyzed for the thermal stresses and appropriate measures shall be taken during fixing the structural system. However, IS codes are silent in terms of process to follow in such kind of designs. To worsen the situation, there are no guidelines available with the design engineers to arrive at design temperature value that should be considered in working out thermal stresses.

Un-cladded three multilevel car park buildings are selected here in order to study the effect of temperature load with respect to length of building. Buildings considered are of length approx. 80m, 160m and 240m. Initially all the three buildings are analyzed and designed for gravity loads in presence of earthquake forces. Then same models are applied with temperature load of 100 C uniformly on all floors. Analysis and design is carried out again in presence of temperature load and results are tabulated. Effect of temperature load on overall deflection, horizontal shear in shear cores, axial forces in beams, axial + bending stresses in slabs are reviewed closely in both the cases. Reinforcement consumption in all load carrying elements viz. flat slab, beams, columns and shear walls is calculated for all the buildings with and without temperature loads. Graphs are plotted to compare the results.

INTRODUCTION

As a standard practice based on IS code, expansion joints are usually provided every after 45m length in case of long buildings. These expansion joints affects the execution of work, construction sequence, façade design (in case of dry cladding/ ACP cladding) and also act as a source of leakage in monsoon during life span of buildings. Expansion joint as used throughout this report refers to the isolation or separation joint provided within a building to allow adjoining segments to expand and contract individually in response to temperature changes without adversely affecting the building's structural integrity or serviceability.

Temperature variation induces stresses in a structure, if the structure is restrained. These stresses vary with the magnitude of the temperature change; large temperature variation can result in substantial stresses that must be accounted for in design, while low temperature changes may result in negligible stresses. Elongation caused by temperature variation can simply be worked out by using relation:

$$\Delta L = \alpha \times L \times \Delta t$$

Where,

ΔL = Elongation due to temperature variation

α = Co-efficient of thermal expansion of concrete (9.9E -06 considered here)

L = Length of building

Δt = Design temperature change

Design temperature change is two third of the difference between the extreme values of the normal daily maximum and minimum temperatures i.e. $2/3(40-25)$ [as per Martin and Acosta,1970]. Martin and Acosta arbitrarily chose the two-third factor to account for the fact that the temperature at which the building is completed would statistically not be at the maximum or minimum daily temperature, but somewhere between the two. Values of maximum and minimum temperature can be referred from Meteorological department of the city. As a case study, data for Mumbai city was referred to arrive at the value of design temperature change.

Basically, buildings can be divided into three separate categories:

- Cladded buildings with controlled temperature like, commercial offices, shopping malls, etc.
- Cladded buildings without temperature control like residential buildings, Industrial estates, schools, colleges, etc.
- Un-cladded buildings like stadiums, sport complexes, multi-level car parks, etc.

Different effect can be seen in the structural design of buildings coming under above categories due to variation in seasonal as well as day and night time temperature variation.

FACTORS AFFECTING EXPANSION JOINT

Following factors generally govern the necessity of the expansion joint in the building:

1. Dimensions and configuration of building
2. Design temperature change
3. Provision for temperature control
4. Type of frame
5. Type of connection with the foundations
6. Symmetry of stiffness against lateral loads
7. Material of construction

BUILDING DESCRIPTION

As described at the beginning of this paper, three identical buildings intended to be used as parking structures without external façade are considered in this parametric study. Number of floors, structural framing at all floors, imposed loads and lateral load parameters are exactly same in all the three buildings. Effects of temperature as varied with the length, three different lengths are considered viz. 80m, 160m and 240m with configuration as Ground + 7 floors + terrace. Being a parking structure, ramps connecting all the floors, passenger elevators and car lifts are considered as a functional requirement. Two staircases are provided for every 80m length of building.

As the structure is proposed to be a multi-level car park building without any external façade, wind loads will not govern the design of building. Hence, structure is analyzed for earthquake load as lateral force in addition to imposed loads along with constant temperature load of 10^0 C.

All structures are considered as RCC flat slab structures with 300mm thick flat slab and 500mm thick drop panels from Level 1 to Terrace. Ground floor is considered as grade slab supported on plinth beams having size 300 x 750mm. All the structural sizes are worked out based on hand calculations made for contributory area, imposed loads and self weight of structure.

Lateral loads are mainly intended to be shared by shear cores. These shear cores are formed by

providing RCC shear walls around car lifts, passenger elevators and staircases. Mechanical, electrical and plumbing services are intended to be carried within a shafts provided in these shear cores. Two way ramp with gradual slope of 1 in 8.4 is provided at the centre of every 80m stretch of building to facilitate inters storey movement of cars. Table 1 describes the important features of these buildings:

Table 1 – Building Features

1.	Type of Structure	Multi-storey pin jointed frame
2.	Earthquake Zone	III
3.	Response reduction factor	5
4.	Importance factor	1
5.	Layout	As shown in Figure 1, 2 & 3
6.	Number of floors	8 (G + 7)
7.	Ground floor height	3.0m
8.	Parking floor height	3.0 m
9.	External walls	1.2m high, 200 thick parapets
10.	Internal walls	200 mm thick concrete block walls
11.	Live load	2.5 kN/m ²
12.	Materials	M 40 and Fe 500
13.	Seismic analysis	Equivalent static method
14.	Design Philosophy	Limit state method conforming to IS 456 : 2000 + IS 13920 : 1993
15.	Size of exterior column	900 x 1500 mm
16.	Size of interior column	900 x 900 mm
17.	Thickness of shear wall	300, 450, 600, 700 as per design requirements
18.	Size of beams	300 x 750 mm
19.	Flat slab thickness	250 mm
20.	Drop panel thickness	500

As per SP 24, clause 35.4.1 of Explanatory Handbook of Indian Standard code of practice for Plain and Reinforced Concrete (IS 456-1978) following load combinations are used considering Limit state of collapse for designing the building against thermal variation:

0.75 (1.05 Dead Load + 1.7 Live Load + 1.4 Temperature Load)

1.4 Dead Load + 1.4 Temperature Load

ANALYTICAL SIMULATIONS & DESIGN

Structural analysis carried out using CSI software Etabs 9.7. Buildings having variable floor plates are selected for this study.

1. Columns and beams modeled as line elements
2. Shear wall and flat slabs modeled as finite shell elements

3. Temperature load assigned to the floor plate/ slabs.

Computer aided design software 'RCDC' from S-cube Futuretech was used to design various structural elements. Based on analysis and design results, various graphs are plotted to discuss the effect of temperature variation with respect to the length of building.

In addition, building was designed for earthquake loads as per IS 1893:2002. As the base shear calculated for wind forces was lesser than base shear calculated for earthquake, wind forces and their combinations have been omitted from this study.

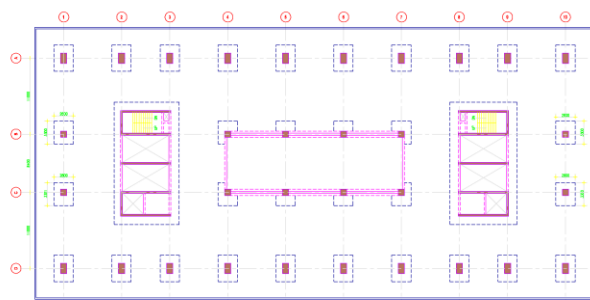


Fig. 1. MODEL I (80m long MLCP building).

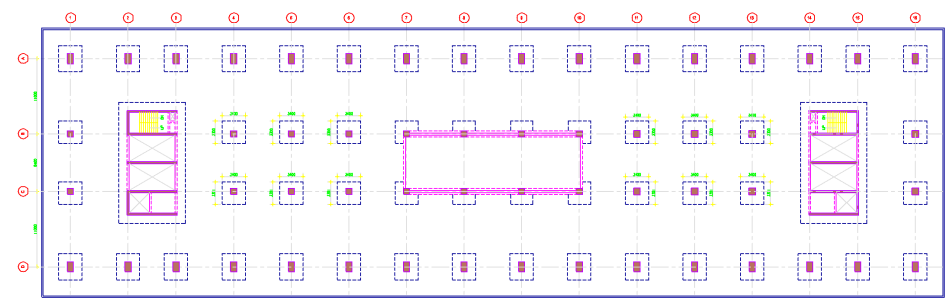


Fig. 2. MODEL II (160m long MLCP building).

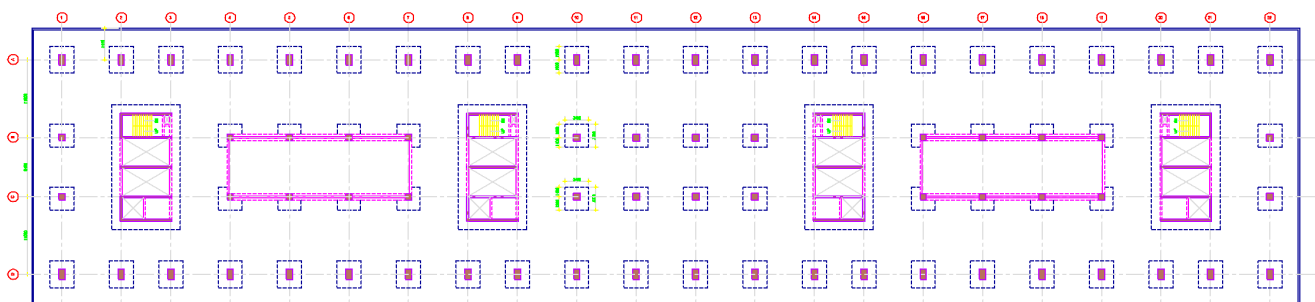


Fig. 3. MODEL III (240m long MLCP building)

RESULTS AND DISCUSSION

Initially, all the three buildings are analyzed and designed with expansion joint without application of temperature load. 160m long building was divided into two separate structures isolated by expansion joints (modeled as physical gap in floor plate). Similarly, 240m long building was divided into three separate structures isolated by expansion joints. All below listed parameters are worked out for these three buildings of 80m, 160 and 240m lengths.

To eliminate the expansion joints, all three buildings are then loaded with temperature load of uniform 10° C. At the same time, separate structures in 160m and 240m long building which were isolated by expansion joint are stitched together eliminating gap left in previously as a expansion joint. All buildings are considered as “Buildings with Dual systems”, with Ductile shear walls and special moment resisting frames (SMRF) as per IS 1893 (Part 1) : 2002, clause 6.4.2. Following parameters are studied and compared on analyzing and designing all the three models for temperature loads in addition to gravity and lateral loads:

- i. Elongation of flat slab
- ii. Design shear in shear walls
- iii. Reinforcement consumption in columns & shear walls
- iv. Axial tension in beams due to temperature load
- v. Design axial tension in beams
- vi. Reinforcement consumption in beams
- vii. Maximum axial stress in flat slab Vs. Modulus of rupture
- viii. Reinforcement consumption in flat slab

Findings against every parameter are described in detail in following sessions along with their graphical representation.

i. Elongation of flat slab:

Extreme top right corner of every model applied with temperature load is selected for comparing elongation experienced by flat slab under ambient temperature condition. Results are tabulated in table 2 for all three buildings. Fig. 4 shows the graphical representation of increase in length of building at every floor on each side along it's length. From this graph, it is clear that higher the length of building expansion experienced by floor plate will be higher. It also observed that expansion increases in all the three building towards terrace as compared with levels below.

Table 2 – Elongation of flat slab under basic load case of temperature load

Story	CASE 1 - 80M			CASE 2 - 160M			CASE 3 - 240M		
	Point	UX	UY	Point	UX	UY	Point	UX	UY
Terrace	166	3.9	1.9	1293	8.0	1.9	1822	12	2
Level 7	166	3.9	1.8	1293	7.8	1.8	1822	12	2
Level 6	166	3.9	1.8	1293	7.6	1.8	1822	11	2
Level 5	166	3.9	1.8	1293	7.4	1.8	1822	10	2
Level 4	166	3.8	1.8	1293	7.0	1.7	1822	9	2
Level 3	166	3.7	1.8	1293	6.4	1.7	1822	8	2
Level 2	166	3.6	1.7	1293	5.5	1.6	1822	7	2
Level 1	166	3.0	1.5	1293	4.2	1.4	1822	5	1

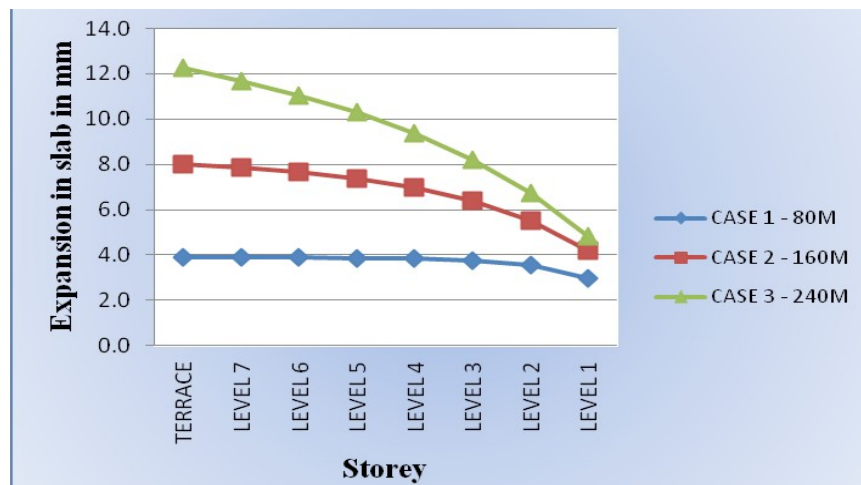


Fig. 4 – Expansion of building under a effect of temperature load

ii. Design shear in shear walls along length:

Pier P1 (Top most pier of extreme left shear core) as highlighted in Fig. 5 is selected as a sample pier in every model to study the effect of temperature load in design of shear walls. Pier P1 is initially designed in all three models without temperature load in existence of expansion joint. Results are tabulated for these cases. Then same pier P1 is designed in all three models applied with temperature load eliminating expansion joints. Again results are tabulated as shown in Table 3 and graph is plotted comparing increase in design shear due to temperature load as shown in Fig. 6.

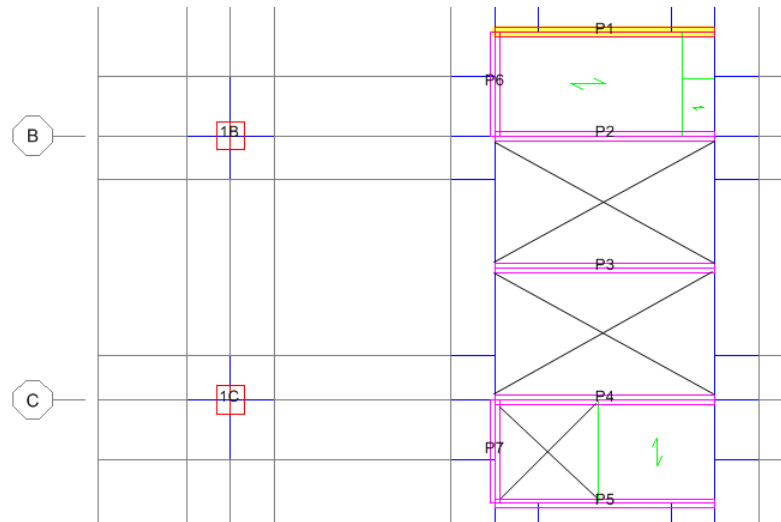


Fig. 5 – Part plan of extreme left shear core in all models

Table 3 – Design shear force in pier P1

Case	Pier ID	With temperature		Without temperature	
		Critical load combi	Design shear KN	Critical load combi	Design shear KN
I – 80m	P1	1.4DL+1.4Temp	6978	1.2(DL+LL-EqY)	2097
II-160m	P1	1.4DL+1.4Temp	12365	1.2(DL+LL-EqY)	2097
III-240m	P1	1.4DL+1.4Temp	14825	1.2(DL+LL-EqY)	2097

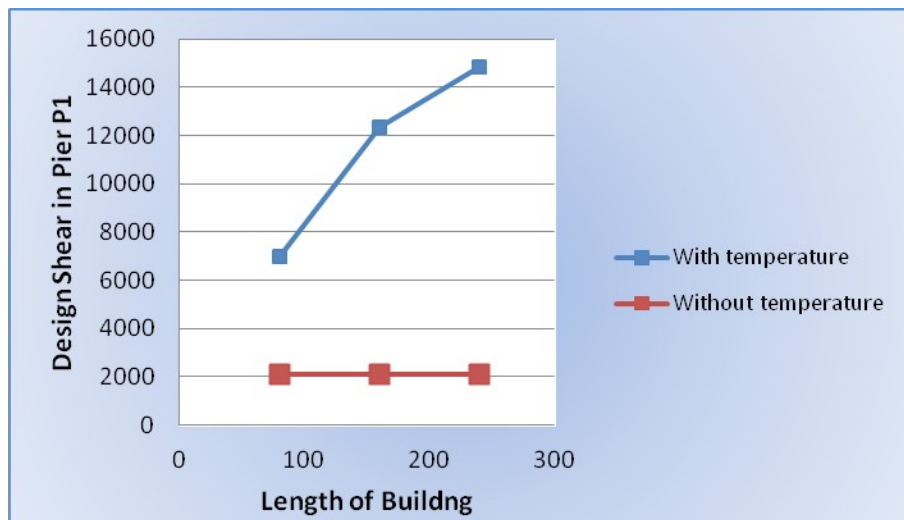


Fig. 6 – Design shear force in pier P1

From the obtained results, it can be confirmed that shear force attracted by shear walls of bottom stories located at extreme end of the building increases with the increase in length of building. To accommodate this increased shear, thickness of shear walls need to be increased as per increased length of building as presented in Fig. 7 below.

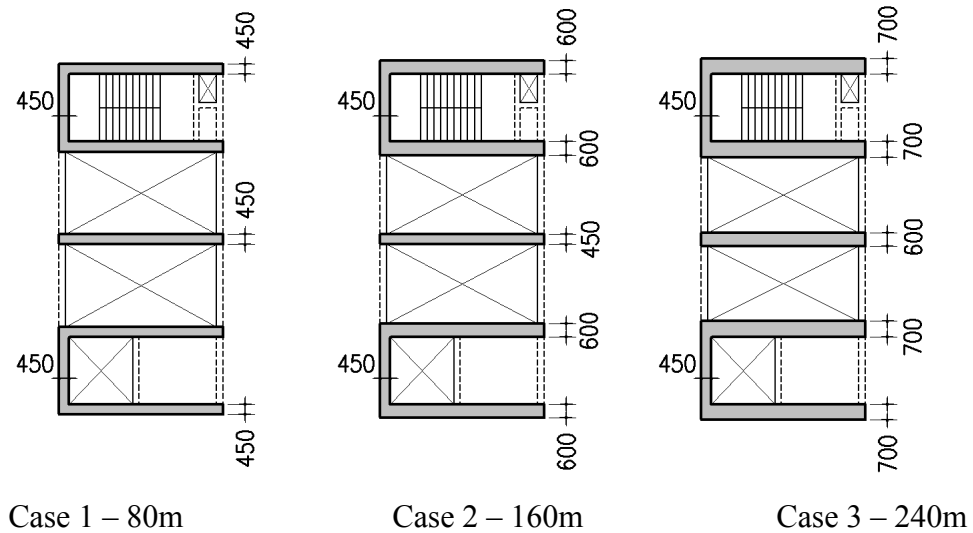


Fig. 7 – Variation in thickness of core wall as per length

iii. Reinforcement consumption in columns & shear walls:

No direct impact was observed on reinforcement consumption in columns and shear wall due to temperature loads. Although the reinforcement consumption in case 1, i.e. Shortest building is found to be high amongst all three, it was justifiable in view of restricted thickness of shear walls in case 1. For case 2 and case 3, shear wall thickness is increased in order to fulfill the requirement of shear along length of building. As a result of which, overall reinforcement consumption in shear wall is marginally reduced in these cases.

In absence of temperature load, expansion joint exists in Case 2 and Case3 creating exactly identical buildings as Case 1. Hence, for case “without temperature”, Case 2 model comprises 2 Case 1 buildings placed next to each, whereas Case3 model comprises 3 Case 1 buildings placed next to each other (separated by expansion joints). This allows keeping reinforcement consumption constant in all the three cases without temperature load.

Table 4 – Reinforcement consumption in columns and shear walls

Case	Length	Steel consumption	
		With temperature	Without temperature
Case 1	80	158.0	156.0
Case 2	160	134.3	156.0
Case 3	240	133.2	156.0

iv. Axial tension in beams:

Fig. 8 shows the graphical representation of increase in maximum axial tension in beam along its length for basic load case of temperature loads. As the length of building increase, marginal increase

in axial tension is observed in beams. Table 5 shows the tabulated results of axial tensile force experienced by beams along the length of building.

Table 5 – Axial tension in beams due to temperature load

Case	Length	Max. Axial Tension for Temperature load
Case 1	80	158.0
Case 2	160	134.3
Case 3	240	133.2

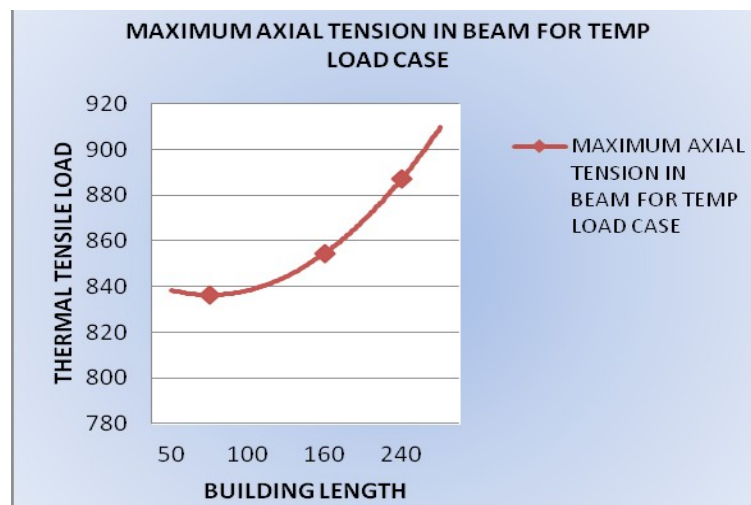


Fig. 8 – Maximum axial tension in beam

v. Design axial tension in beams:

Figure 9 represents the axial force experienced by beam for all the design load combinations including lateral loads. When buildings are analyzed without considering effect of temperature loads, design axial force is somewhere in the range of 200 KN. Whereas if the same buildings are analyzed after applying temperature loads, axial forces in beams increases up to 1200 KN. (e.g. Beam B1) in critical load combination. It clearly indicates that the building analyzed with temperature load carries heavier axial tension in beams as compared with buildings without temperature load. However, no measure variation was found in axial forces with respect to increase in length of the buildings.

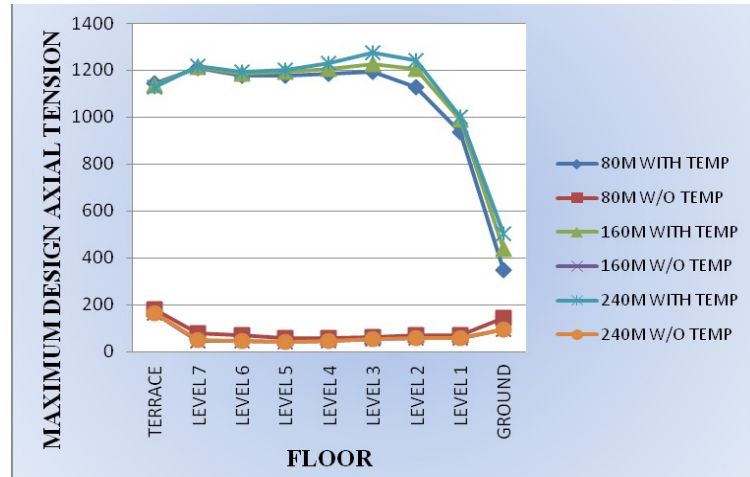


Fig. 9 – Maximum design axial tension in beam

vi. Reinforcement consumption in beams:

Figure 10 represents the increase in reinforcement consumption in beams for all the three models with and without temperature loads. Selected beams (beam B1) at ground floor, typical floor and terrace floor were designed using two design approaches, viz. Simple bending theory and Bi-axial bending theory with axial forces (similar to columns subjected to tension + moments). In view of significant increase in axial tension, these beams shall not be designed only for bending. Effect of axial tensile force must be taken into consideration during beam design. As a result, about 12% increase in overall reinforcement consumption was observed in 80m long building whereas the same was found to be 25% in 160m and 240m long building. Exact values are tabulated in Table 6 below.

Table 6 – Axial tension in beams due to temperature load

Case	Reinforcement Consumption		% Increase
	With temperature	Without temperature	
Case 1 - 80m	230.3	204.5	12.6
Case 2 - 160m	223.9	178.1	25.7
Case 3 - 240m	224.8	177.7	26.5

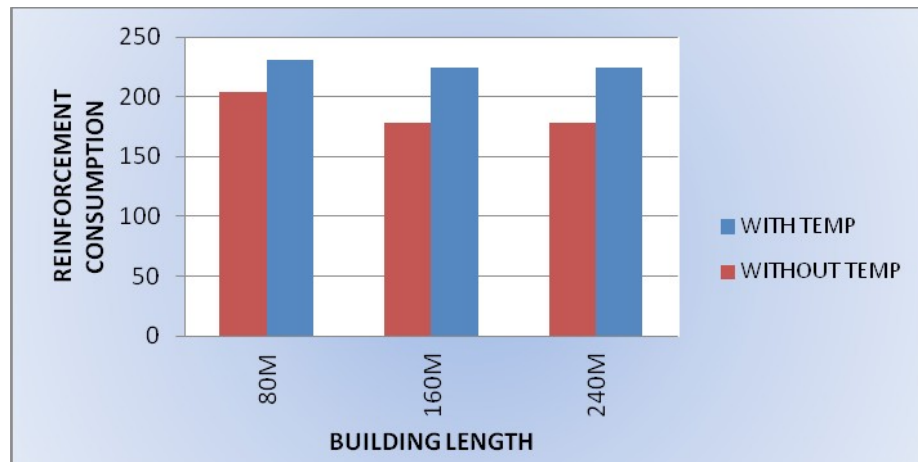


Fig. 10 – Reinforcement consumption in beams

vii. Maximum axial stress in flat slab Vs. Modulus of rupture:

Figure 11 represents the maximum axial tensile stress in a typical flat slab middle strip at Terrace floor level due to temperature load. It clearly indicates that the stress level increases with length of the building. Structural designer has to keep a tab on this value as it should not exceed beyond modulus of rupture given by equation:

$$\text{Modulus of Rupture} = 0.75 * \sqrt{F_{ck}}$$

Table 7 describes maximum axial tension experienced by flat slab middle strip along with calculation of axial tensile stress.

Table 7 – Axial tensile stress Vs. Modulus of rupture

Case	Length 'm'	Max. axial tension due to temperature load kN	Max. Axial Tensile Stress N/sq.mm	Moduls of Rupture N/sq.mm
Case 1	80	742	2.47	4.43
Case 2	160	1016	3.39	4.43
Case 3	240	1047	3.49	4.43

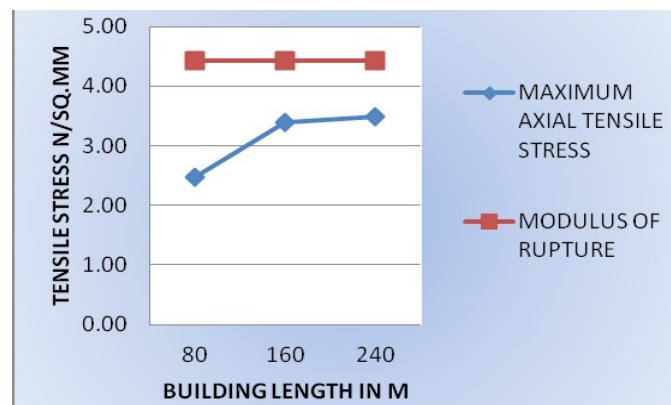


Fig. 11 – Axial tensile stress Vs. Modulus of rupture

viii. Reinforcement consumption in flat slab

Figure 12 represents the increase in reinforcement consumption in flat slab at two different levels. Level 1 was selected representing normal loading conditions of typical parking floor, i.e. 100mm thick floor finish + services + Live load of 2.5Kpa. To study the similar effect, terrace floor was also considered having additional imposed load due to waterproofing. In both the case, it is observed that reinforcement consumption goes on increasing with increase in length of building. Overall increase is found to be about 12% to 15% for 80m building, 18% to 22% for 160m long building and about 25% to 30% for 240m long building. Tabulated results for this calculation are presented in Table 8 and Table 9 below.

Table 8 – Reinforcement consumption in flat slab at level 1

Case	Length 'm'	Reinforcement Consumption @ level 1		% increase at level 1
		Without temperature	with temperature	
Case 1	80	57.15	63.9	11.81
Case 2	160	100.56	118.88	18.22
Case 3	240	150.11	188.33	25.46

Table 9 – Reinforcement consumption in flat slab at Terrace

Case	Length 'm'	Reinforcement Consumption @ terrace		% increase at terrace
		Without temperature	with temperature	
Case 1	80	57.38	66.06	15.13
Case 2	160	105.23	128.42	22.04
Case 3	240	153.55	200.65	30.67

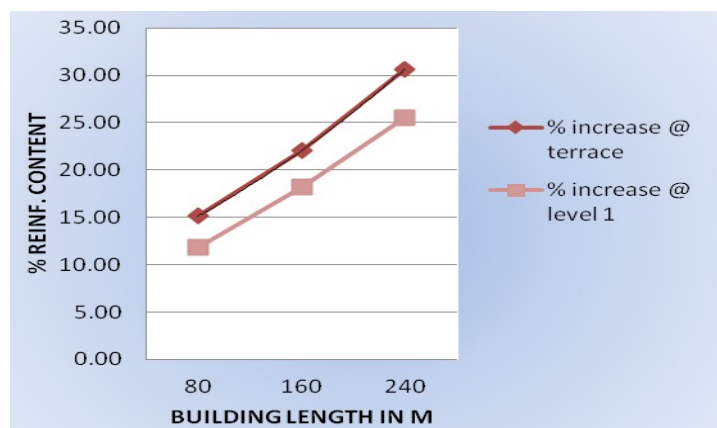


Fig. 12 – Reinforcement consumption in Flat slab

CONCLUSION

The behaviors of multistoried car park building exposed from all sides without any cladding, with & without temperature loads for various lengths have been studied in present scope of work. This study has clearly highlighted effect of temperature load in structural design of individual element and overall structural system. Basically, increase in length of building beyond permissible limit of 45m as per IS 456 : 2000, impacts on structural sizing, design shear in shear walls at extreme ends and reinforcement consumption in bending elements like beams and floor slabs.

It is also found that the floor beams placed along the length of building experiences heavy axial tension in addition to shear force and bending moments. It becomes mandatory in this case to design the beam as per column design theory which considers effect of axial force + uniaxial or biaxial bending. As a result, percentage reinforcement increases in case of beam design subjected to temperature loads.

In case of flat slabs, effect of temperature load was found to be as same in case of beams. Column strips/ middle strips experiences heavy axial tension in addition to bending moments due to thermal variation. If this axial tension generates tensile stress more than modulus of rupture of concrete, there will always be possibility of haphazard cracks on surface of slabs which may lead to partial/ full collapse of flat slab.

REFERENCES

1. *“Expansion joints in Buildings,”* Technical Report No. 65, National Academy of Sciences, Washington D.C., 1974 prepared by the Standing Committee on Structural Engineering of the Federal Construction Council
2. Malcolm J. S. Hirst, M.ASCE, *“Thermal Loading of Concrete Roofs”*, April 1980
3. *“SP : 24 – 1983”*, Explanatory Handbook on Indian Standard Code of Practice for Plain and Reinforced concrete
4. Pfeiffer, Michael J. and Darwin David, *“Joint design for Reinforced concrete buildings”* SM Report No. 20, University of Kansas Center For Research, Lawrence, KS, Dec 1987
5. *“BS 8110 – Part 2”*, British Standard Code of Practice for special circumstances published in 1985, amended in July 2001

6. Edward G. Nawy, D.Eng., P.E., C.Eng, "*Joints in Concrete Construction*", Concrete Construction Engineering Handbook, Second edition,
7. "*IS 3414: 1995*," Indian Standard code of practice for Design and Installation of joints in Buildings
8. "*ACI committee 224.3r-95*", Joints in Concrete construction. American Concrete Institute, Farmington Hills, MI, 2005, pp 1-44
9. "*IS 456 – 2000*", Indian Standard code of practice for Plain and Reinforced concrete
10. James M. Fisher, S.E., "*Expansion joints: Where, When and How*", April 2005
11. Bill Faschion and Nayan Trivedi, "*Temperature and shrinkage study for 300m long building*" For M/s. Tishman Speyer Inc for their project in Hyderabad, India
12. Mohammed Iqbal, D.Sc, P.E., S.E., Esq. "*Design of expansion joints in Parking structures*", October 2010
13. "*Considerations in Expansion Joint system selection*", by Tech Topic series of ERIE METAL SPECIALTIES, August 2010
14. ACI Committee 318.2011. *Building code requirements for structural concrete and commentary*, ACI 318-11. American Concrete Institute, Farmington Hills, MI
15. "*Expansion joint... Why Bother?*" By Davco Construction Materials in May 2007
16. Paul Millman, Robert Kilcup A.M.ASCE and C. Allin Cornell, M.ASCE, "*Design Temperature for Structural Elements*", April 1980
17. Maria Anna Polak, "*Thermal Analysis of Reinforced Concrete Shells*", April 1980
18. Bilig, K. 1960, "*Expansion joints In structural concrete*", Macmillan, London
19. Zdenek P. Bazant and Maurice F. Kaplan, "*Concrete at High Temperature: Material Properties and Mathematical models*", 1996
20. Jack Emanuel, F.ASCE & Charles M. Taylor, A.M.ASCE , "*Length – Thermal stress relations for composite bridges*"
21. Reynolds, C.E. 1960. *Reinforced Concrete Designer's Handbook*, 6th ed. Concrete Publications, London
22. Lewerenz, A.C. 1907. *Notes on Expansion and contraction of concrete*, Eng. News, 57 (19),512-514

23. Mann, O.C. 1970. *Expansion-contraction joint locations in concrete structures*. In Proceedings of symposium on Designing for the effect of Creep, shrinkage, and Temperature in Concrete Structures, SP-27
24. PCA. (1982). "*Building movements and joints*", Portland Cement Association, Skokie, IL, 64pp
25. PCA. (1992) Joint "*Design for Concrete Highways and Street Pavements*", Portland Cement Association, Skokie, IL, 13pp
26. Merrill, W.S. 1943, "*Prevention and control of cracking in Reinforced Concrete Buildings*", Eng News-Record, 131, 91-93