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The Thermal Response of Multi-Storeies Concrete Frame Building in the Arabic Area

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Abstract: In this paper, there will be an analysis study to figure out the impact of the environment thermal loads, shrinkage and creep at multi-storeies reinforced concrete frame buildings in the Arabic area. Etabs models will be prepared based on NTDP and TDP of ordinary concrete, considering two columns heights as 3m and 6m, and two supports conditions as fixed and hinged to define the major aspects affect the thermal response of multi-storey concrete frame buildings concentrating at the thermal deformations and the columns reactions, then it will be compared with the thermal response of existing concrete building considering both methodologies of TDP as per CEBFIP99 and NTDP as per ACI Committee to define the optimum methodology to be recommended and followed The generated Etabs models confirmed that the time dependent properties method is the optimum with a clear conversion between time dependent properties model and the existing parking thermal deformations. increasing the thermal reaction forces at column supports reduces the correlated thermal displacements due to stiffness increment of the entire building, The first-level displacements of multi-storey buildings are slightly smaller than those of upper levels and single-storey buildings, but the displacements of the second level are slightly larger than those of the other levels. Meanwhile, the displacements of levels above the second storey are close to the displacements of single-storey models. Overall, there are small differences between multi- and single-storey models,. finally, the importance of analyzing thermal loads fluctuation at columns reactions for multi storeies buildings whereas the reactions of multi storeies cannot be predicted from single storey analysis.

Keywords: Time Dependent, Thermal; Diversion; Strains

I. INTRODUCTION

It is essential for design to understand the behavior of reinforced concrete at early stages of construction and at whole life span of the structure, the concrete properties are not constant values, the mechanical properties vary with time in function of the progress of hydration process. This includes the concrete strength, the modulus of elasticity, shrinkage and creep [1]. Defining the structural behavior of a concrete structure over the course of its estimated lifespan is a fascinating phenomenon.

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It is important to mention that CEP FIP,1999 code [2] provides complete process for time dependent properties of concrete considering creep effects and coefficients, with variable values of concrete strengths. The CEB FIP code includes figures for total shrinkage over the building lifespan in concrete structures in addition to values of concrete creep coefficient. It will be inserted in ETABS model, time dependent properties input values. The effectiveness of the expansion joints was measured by researchers whereas they got that increasing the number of expansion joints by reducing the spacing between the joints improves its effectiveness [4] which may justify the variances of allowed spacing between joints in different codes. The spacing requirements listed in codes are smaller than those for modern or unique buildings. Moreover, whilst PCA (1982) and Dubai municipalities prescribe a maximum spacing of 60 m, other standards allow much smaller spacings such as ACI 350R Committee with a maximum spacing of 36 m. Increasing such spacing requirements is possible based on the results of finite element models to meet the requirements of modern unique buildings whereas FEM is recommended methodology for similar phenomena analysis and conclusions [6].

This significant response is noticed in constrained slabs while the effect of temperature fluctuation is ignored in non-restrained slabs. It is clear that the loads of temperature are composed of two main parts, these parts will be considered in my analysis too. The 1st part is related to seasonal climate changes and the 2nd part is related to shrinkage impact and equivalent thermal effects [4]. Superposition and interaction of humidity and temperature changes with the creep and the shrinkage of concrete are with similar nature. they impose increment in concrete deformations and creep [5] (Bazant and et al,1997).

II. METHODOLOGY

A. *Used Methods*

The annual thermal expansion coefficient value is approximately 1.852 of the correlated seasonal coefficients, and the correlated average value is 9.5×10^{-6}, as determined by various tests on unrestrained concrete samples with different reinforcement compositions, cement types, and aggregate sizes [7]. Accordingly, this figure will be inserted in FEM model. The cylinder strength of used concrete fc' is 40 N/mm2 with elasticity modulus of 30000 N/mm² as per American concrete institution and used codes in Arabic region The mass of concrete per unit volume is 2400 kg/m3. The used temperature fluctuation between summer and winter, The design temperature maximum daily variation is: whereas Ts is -17(C°)=-30(F°) for drying shrinkage consideration. The design temperature with maximum daily variation is 9-43=-34(C°) as shown in Fig. (1). while Ts is 17(C̊), the total variation will be

$$\Delta T=\frac{2}{3}(\mathrm{Tmax}-\mathrm{Tmin})+\mathrm{Ts}=22.6+17=39.7C^{\circ}.$$

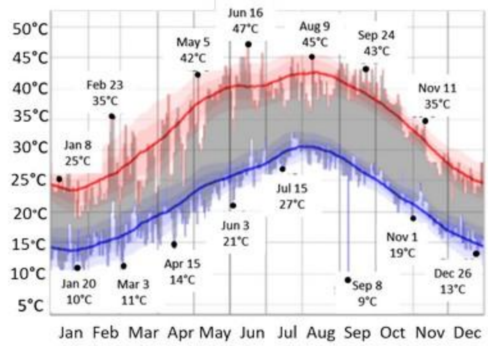

Fig. 1.Fluctuations in environmental temperature reported in 1997 (A.D.I.A, 2015) [5]

To recognize the impact of temperature variations on the displacements of multistorey structures and correlated reactions, a comprehensive analysis was undertaken based on Etabs program. Consequently, three-dimensional multi-story concrete buildings are generated. The perspective and plan view are shown in Figures (2) and (3). A comparison of external columns displacements. and the reactions results is presented for the columns M, N and O. at axis (a). These columns are shown in figure (3) which have the most critical values than internal columns. The reactions and the deformations of columns at axis (a) are similar to reactions and deformations at slab edge at axis (k) too (edge columns will suffer from maximum stresses and deformations under thermal loads).

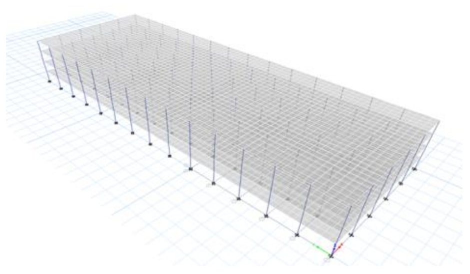

Fig. 2.Three dimensional view of the Etabs model for multi-storeies reinforced concrete frame building

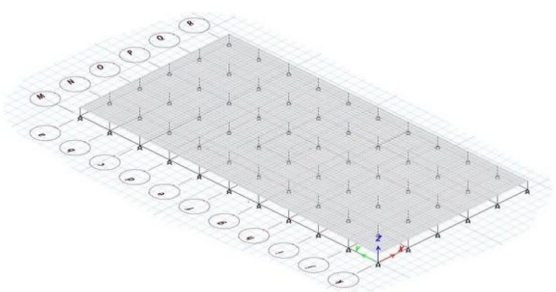

Fig. 3. The two dimensional view of the concrete frame byulding in Etabs model

III. RESULT AND DISCUSSION

A. Displacements at columns M, N and O

The thermal displacements (UY) for columns M, N, and O are clarified in tables (I) and (II). The displacements in figure 3 are on the same side of the axis Y. Table I shows the results of three-dimensional multi-story concrete frame buildings with hinged columns, while table II shows the deformations of three-dimensional multi-story finite element models with fixed columns conditions. The slabs come in two thicknesses: 300mm and 400mm. The heights of column are 3 and 6 meters. At the exterior columns M, N, and O, distinct values of thermal deformations are induced.

Table-I: Thermal displacements UY(M), UY(N), and UY(O) in (mm) for constructions with hinged supports and 300 mm thick floors at all levels

Slab Length(m)	Hinged support							level
	Height of columns (3m)			Height of columns (6m)				
	UYM	UYN	UYO	UYM	UYN	UY O	$\Delta_{\circ}$	
50	9.902	9.902	9.902	9.9	9.9	9.9	10	4th
60	11.871	11.871	11.871	11.9	11.9	11.9	12	
80	15.8	15.8	15.8	15.8	15.8	15.8	16	
100	19.76	19.76	19.76	19.8	19.8	19.8	20	
120	No need, deformation exceeded allowed limit 16.67mm			23.8	23.8	23.8	24	
140				27.7	27.7	27.7	28	
160				31.7	31.7	31.7	32	
180				35.6	35.6	35.6	36	
200				39.6	39.6	39.6	40	
50	9.87	9.87	9.87	9.9	9.9	9.9	10	3rd
60	11.88	11.88	11.88	11.9	11.9	11.9	12	
80	15.9	15.9	15.9	15.8	15.8	15.8	16	
100	20.1	20.1	20.1	19.8	19.8	19.8	20	
120	No need, deformation exceeded allowed limit 16.67mm			23.7	23.7	23.7	24	
140				27.7	27.7	27.7	28	
160				31.7	31.7	31.7	32	
180				35.6	35.6	35.6	36	
200				39.6	39.6	39.6	40	
50	10.1	10.1	10.1	10	10	10	10	2nd
60	12.3	12.3	12.3	12	12	12	12	
80	16.4	16.4	16.4	16	16	16	16	
100	20.65	20.65	20.65	20.1	20.1	20.1	20	
120	No need, deformation exceeded allowed limit 16.67mm			24.1	24.1	24.1	24	
140				28.3	28.3	28.3	28	
160				32.5	32.5	32.5	32	
180				36.6	36.6	36.6	36	
200				40.7	40.7	40.7	40	
50	9.22	9.34	9.37	9.8	9.8	9.8	10	1st
60	10.94	11.1	11.14	11.7	11.7	11.8	12	
80	14.17	14.47	14.49	15.5	15.6	15.6	16	
100	17.24	17.6	17.65	19.2	19.3	19.4	20	
120	No need, deformation exceeded allowed limit 16.67mm			22.9	23.1	23.1	24	
140				26.5	26.7	26.7	28	
160				30.1	30.2	30.3	32	
180				33.5	33.7	33.8	36	
200				36.6	37.1	37.2	40	

Table- II: Thermal displacements UY(M), UY(N), and UY(O) in (mm) for constructions with fixed supports and 300 mm thick floors at all levels

Slab Length (m)	Fixed support						$\Delta_{\circ}$	level
	Height of columns (3m)			Height of columns (6m)				
	UYM	UYN	UYO	UYM	UYN	UYO		
50	9.9	9.9	9.9	9.902	9.902	9.902	10	4th
60	11.9	11.9	11.9	11.88	11.88	11.88	12	
80	15.816	15.816	15.816	15.84	15.84	15.84	16	
100	19.78	19.78	19.78	19.80	19.80	19.80	20	
120	No need, deformation exceeded allowed limit 16.67mm			23.8	23.8	23.8	24	
140				27.7	27.7	27.7	28	
160				31.7	31.7	31.7	32	
180				35.6	35.6	35.6	36	
200				39.6	39.6	39.6	40	
50	9.9	9.9	9.9	9.88	10	9.88	10	3rd
60	11.9	11.9	11.9	11.85	12	11.85	12	
80	16	16	16	15.8	16	15.8	16	
100	20.2	20.2	20.2	19.75	20	19.75	20	
120	No need, deformation exceeded allowed limit 16.67mm			23.7	23.7	23.7	24	
140				27.69	27.69	27.69	28	
160				31.7	31.7	31.7	32	
180				35.6	35.6	35.6	36	
200				39.75	39.75	39.75	40	
50	10.2	10.2	10.2	10	10	10	10	2nd
60	12.3	12.3	12.3	12.01	12.01	12.01	12	
80	16.35	16.35	16.35	16	16	16	16	
100	20.3	20.3	20.3	20.18	20.18	20.18	20	
120	No need, deformation exceeded allowed limit 16.67mm			24.3	24.3	24.3	24	
140				28.5	28.5	28.5	28	
160				32.7	32.7	32.7	32	
180				36.6	36.6	36.6	36	
200				40.8	40.8	40.8	40	
50	8.3	8.5	8.6	9.58	9.64	9.66	10	1st
60	9.6	9.9	10	11.39	11.49	11.52	12	
80	11.9	12.48	12.58	14.89	15.1	15.1	16	
100	13.99	14.68	14.8	18.24	18.5	18.55	20	
120	No need, deformation exceeded allowed limit 16.67mm			21.5	21.8	21.87	24	
140				24.54	24.89	24.95	28	
160				27.3	27.7	27.8	32	
180				32.5	32.7	32.8	36	
200				32.6	33.1	33.2	40	

The deformations of the 2nd storey are slightly more than the other levels deformations (1st, 3rd and 4th). Deformations of the upper levels above the 2nd storey seem very close to the 1st storey displacements. Third and fourth levels deformations at all columns M, N and O have very close values with respect to the column height. The deformations of column O for all different slabs lengths from 50 to 200m are more than other analyzed columns M and N displacements at 1st storey level. For columns with hinged support, the biggest displacements are not detected at a specific column, whereas all studied displacements are nearly identical at the same level, whereas critical displacements for columns with fixed support are observed at column O at 2nd level as shown in table II. As a result, column displacements in multi-story concrete structures must be calculated using the maximum thermal displacements at the internal peripheral columns rather than the corner column. The columns M, N and O horizontal displacements above 1st slab level are close to $\Delta_{\circ}$

$$\Delta_{\circ} = \frac{1}{2} L.\alpha.\Delta t \qquad (2)$$

$\Delta_{\circ}$ is thermal deformation for unrestrained slabs. It is used in Arabic region for quick calculations of thermal displacements. It is obvious that thermal strains at different levels have minor differences, so we can predict the thermal deformations from single storey models and utilizing same observations and equations formulas for deformations of single storey moment frame buildings at multi-storeies buildings. Consequently, we can use same allowed expansion joints spacing for single storey to be implemented in multi-stories buildings. whereas expansion joints spacings between two adjacent segments of the building are limited to the maximum allowed lateral deformations of H/180.

B. Reaction forces at columns M, N and O

Tables III and IV present the thermal reaction forces (FY) at columns M, N and O for fixed and hinged columns supports respectively. These reactions are on the same side of the axis Y.

Table- III: Reactions FY(M), FY(N)&FY(O) in (KN) for constructions with fixed supports and 300 mm thick floors

Slab length. (m)	Fixed column supports							
	Height of columns (3 m)				Height of columns (6 m)			
	FY (M)	FY (N)	FY (O)	Ratio FY (M/O)	FY (M)	FY (N)	FY (O)	Ratio FY (M/O)
50	1750	1868	1891	93%	313	322	323	97%
60	1978	2137	2165	91%	369.5	382.88	384	96%
80	2362.5	2585	2620	90%	476	497	499	95%
100	2667	2935	2975	90%	576	603	606	95%
120	2912	3213	3257	89%	675	709	712	95%
140	3113	3440	3485	89%	759	799	802	95%
160	3281	3626	3674	89%	825	870	873.5	94%
180	3424	3785	3834	89%	890	940	930	96%
200	3547	3922	3972	89%	955	1008	1012	94%

Table- IV: Reactions FY(M), FY(N)&FY(O) in (KN) constructions with hinged supports and 300 mm thick floors

Slab length (m)	Hinged column supports							
	Height of columns (3 m)				Height of columns (6 m)			
	FY (M)	FY (N)	FY (O)	Ratio FY (M/O)	FY (M)	FY (N)	FY (O)	Ratio FY (M/O)
50	462	490	494	94%	73.5	76	76	97%
60	531	569	575	92%	87.3	90.9	91.3	96%
80	652	707	714	91%	114	119.3	119.6	95%
100	755	824	833	91%	139.3	146.3	146.8	95%
120	843	924	933	90%	165.5	174.6	175.1	95%
140	920	1010	1020	90%	188.5	199.3	200	94%
160	986	1085	1096	90%	210	222.6	223.2	94%
180	1045	1152	1163	90%	230	244.5	245	94%
200	1100	1250	1260	88%	249.5	265	266	94%

Tables III and IV show that the lateral reaction forces have different values at analysed columns (M), (N) and (O) throughout all models. The reactions at Columns (N) and (O) almost have small variances especially in hinged models. The reaction of column (M) appears to be smaller than the response at the other analysed columns (N) and (O). The response ratio of column (M) to columns N and O ranges from 88% to 97% for hinged and fixed column conditions respectively. This provide a logic prediction of the effect of these loads on the dimensions of correlated columns and foundations. overall, hence the imposed thermal reaction forces at column O AT center of slab edge exceed those induced at columns M and N under fixity conditions, the reactions from column O will be analysed precisely in this paper.

C. Conclusions of thermal reactions in multi-storey structures

This paragraph shows the findings of ambient temperature changes in the Arabic area on most critical column reaction forces. The study results are presented in Figures 4 and 5.

Temperature changes as defined in Figure 1 based on thermal fluctuations in environmental temperature reported in 1997.

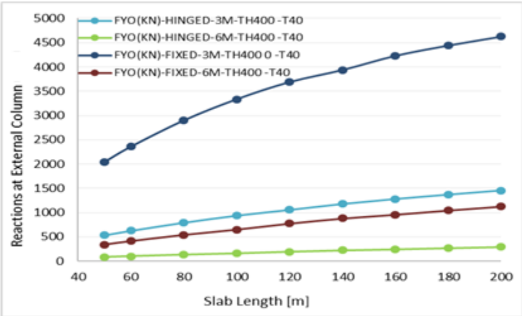

Fig. 4. Thermal reactions (FY) for all models with a slab thickness of 400 mm at external column.

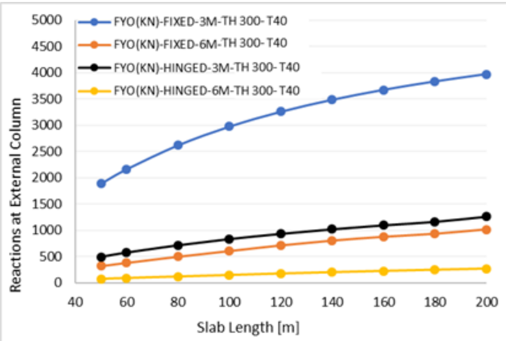

Fig. 5. Thermal reactions (FY) for all models with a slab thickness of 300 mm at external column.

It is clear that concrete frames result with fixed supports conditions and three meters of storey height impose the largest and the most critical values of reactions. Regarding the impact of the building height at the lateral reaction result of multi-stories concrete frame building, table V shows that horizontal reactions related to fixed columns conditions with 3m height are 5 to 5.85 times larger than reactions of models with column heights of 6 m and fixity conditions. This ratio increased to around 11 for hinged conditions models. Finite element models showed that this ratio will increase with the slab length reduction. It is reduced from 11.5 to 10.30 for models with 50m slab length.

Table- V: Ratios of 3m column height reactions to 6m columns height for multi-storeies concrete buildings

SlabLength (m)	Fixed conditions		FYO (3m) / FYO (6m)	Hinged conditions		FYO (3m) / FYO (6m)
	Column Height (6m)	Column Height (3m)	Ratio %	Column Height (6m)	Column Height (3m)	Ratio %
	FYO	FYO		FYO	FYO	
50	323	1891	5.8	76	877	11.5
60	384	2165	5.6	91	1026	11.2
80	499	2620	5.2	119	1290	10.8
100	606	2975	4.9	146.8	1514	10.3

Regarding the impact of columns condition support at lateral reaction result of multi-stories concrete frame building, table VI shows that thermal reaction forces related to fixed column supports with 6m height are 4 times greater than those of hinged supports with same columns height. This ratio reduced to around 2 for models with 3m columns height. Finite element models showed that this ratio will increase slightly with the slab length reduction. It is increased from 3.8 for slab length 200m to 4.25 for models with 50m slab length and column height 6m, this increment is observed too for 3m columns height models whereas it increased from 1.96 for slab with length 100m to 2.15 for the slab with 50m length.

Table- VI: Ratios of fixed columns reactions to hinged columns for multi-storeies concrete buildings

Slab Length (m)	Hinged column	Fixed column	FYO Fixed /FYO Hinged	Hinged columns	Fixed column	FYO Fixed /FYO Hinged
	Columns Height (6m)		Ratio	Columns Height (3m)		Ratio
	FYO (KN)	FYO (KN)	%	FYO (KN)	FYO (KN)	%
50	76	323	425%	877	1891	215
60	91	384	422%	1026	2165	211
80	119.6	499	417%	1290	2620	203
100	146.8	606	413%	1514	2975	196
120	175.1	712	407%	No need, deformation exceeded allowed limit 16.67mm		
140	200	802	401%			
160	223.2	873.5	391%			
180	245	930	380%			
200	266	1012	380%			

According to the preceding tables, increasing the thermal reaction forces at column supports reduces the correlated thermal displacements due to stiffness increment of the entire building. These results confirm the importance of analyzing thermal loads fluctuation at columns reactions for multi storeies buildings whereas the reactions of multi storeies cannot be predicted from single storey analysis and the columns and foundations are subjected to high horizontal reactions which has major impact at correlated size and integrity.

D. Analytical Discussion of Experimental Study Results and Finite Elements Models

A comparison study between Etabs finite elements models for existing parking building and the registered tests results of Aboumoussa and Iskandar [2] experimental study for the thermal response of same existing building within period of five years will be presented. 3D Etabs models will be generated based on NTDP and TDP of ordinary concrete concrete. The results of Etabs finite elements models will be compared with actual thermal response of this building which was presented in Aboumoussa and Iskandar study to get a conclusion about recommended method for predicting thermal responses of concrete frame buildings. Four sensors are fixed in the experimental study, two sensors are at roof level while the others at level C (the third slab level) adjacent to the expansion joint edge. These sensors register the thermal displacement of the expansion joint at the north and the south parts of this building. Four Etabs models are generated based on NTDP and TDP of ordinary concrete and reflecting the maximum variation of temperature for each sensor at north side of the building and at the south side too.

Figure 6 clarifies displacement at level ©-south part of the building in Etabs non-time dependent properties (N.T.D.P) models, figures 7 and 8 present thermal displacements at roof level for sensor fixed at south part of the building for 4.5 years and 70 years respectively, While Figures 9 and 10 display thermal displacements at level C for sensor fixed at south part of the building for 4.5 years and 70 years respectively
Fig. 6. Horizontal displacement at level ©-south part of the building in Etabs N.T.D.P

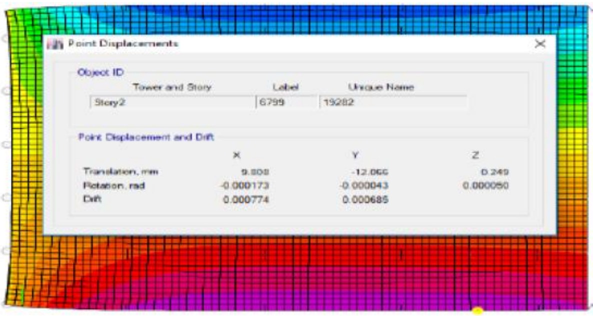

Fig. 6. Horizontal displacement at level ©-south part of the building in Etabs N.T.D.P

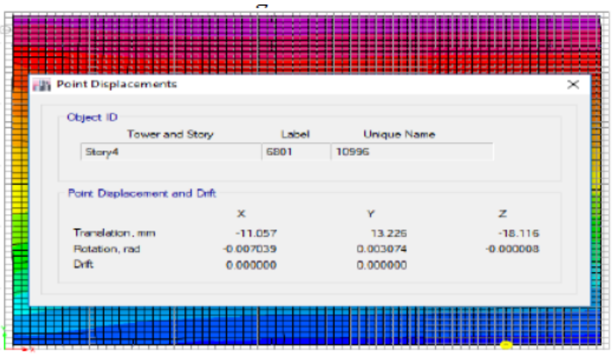

Fig. 7. displacement at roof level-south part of the building in Etabs T.D.P models for period 4.5 years

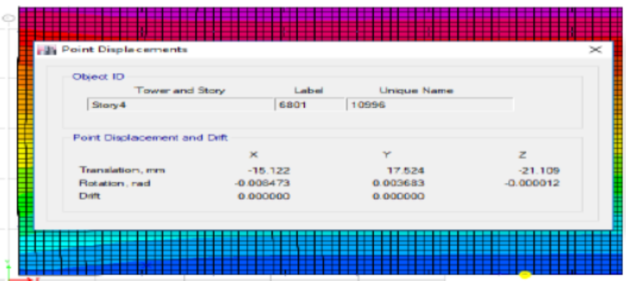

Fig.8. displacement at roof level-south part of the building in Etabs T.D.P models for period 70 years

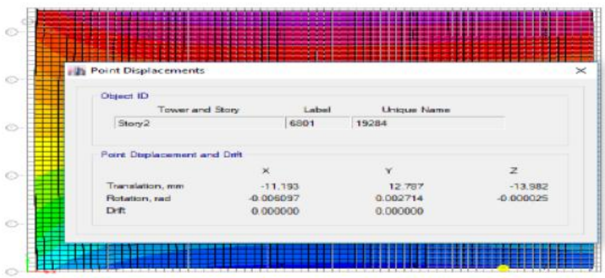

Fig. 9. displacement at level C-south part of the building in Etabs T.D.P models for period 4.5 years

Fig.10. displacement at level C-south part of the building in Etabs T.D.P models for period 70 years

Table VII shows all ranges of displacements at the tests locations including all different methods. Firstly, the finite element models with non-time-dependent properties of concrete, then the time-dependent properties models with two different periods 4.5 and 70 years and finally the empirical test results by Aboumoussa and Iskandar. The displacements at north side seem very small, the allowed limit is h/180=2750/180=15.27mm, all values within 4.5 years period are lesser than 6mm. The north side displacements are. not critical in all methods due to existence of huge retaining wall at north side, this wall reduced thermal displacements, small value of displacements don't have impact at expansion joint location, so north side is not the critical one.
The range of displacements at south side of the building are close to the allowed limit h/180=2750/180=15.27mm. This side deformations are the critical with direct impact at expansion joint location. The used methods presented different values of displacements. It is clear that the displacement of time-dependent ETABS model with 4.5 years period is very close to test results with 1mm approximately difference, while non-time-dependent properties model's results are lesser than tested results within 4.5 Years, so N.T.D. P. don't represent the deformations of all span life of the building since it is even lesser than imposed displacement within 4.5 years. The predicted deformations within 70 years are about 17.5mm, they exceeded the allowed limit 15.27mm. It is clear that the expansion joint location is not within code requirements CEB-FIP for 70 years period, it can be categorized as a reason for observed cracks within this building during its service life.

Table- VII: The range of displacements in (mm) at tested sensors and finite elements models considering T.D.P and N.T.D.P

Sensor side and level	N.T.D.P models	T.D.P. models		Test -sensors results Aboumoussa and Iskandar 2012
		4.5 years	70 years	
	UYM(mm)	UYM(mm	UYO(mm)	Δ_o(mm)
Roof -south	11.989	13.226	17.524	14.85
level C-south	12.06	12.787	17.191	13.89
Roof -north	5.5	5	14	0.08
level C-north	6	6	13	0.08

IV. CONCLUSION

The fluctuation of temperature loads cause various lateral displacements on the external columns at slab edge on the first slab level. The transition is obvious in the registered displacements, but it is not the same. This variance increases in fixed models than hinged models. The thermal reaction forces at column (M) is smaller than those at columns (N) and (O). The size of foundations and columns for models with fixed conditions can be identical under thermal loads while the difference in the elements design is observed in structures with hinged supports. The thermal displacements rise with length of the floor slab and the height of the storey. The displacements of the 1st level of multi-storeies are almost identical with single storey models. the deformations at the 2nd storey are slightly more than the other levels deformations (1st, 3rd and 4th). Deformations of the upper levels above the 2nd storey seem very close to the 1st storey displacements. It leads to same allowed values for spacing between expansion joints for both single and multi-stories concrete frame buildings. For multi-storeies buildings, the thermal reaction forces induced at column (M) by thermal variation are smaller than those at columns (N) and (O). the ratio of thermal reaction of Column M reaction to columns N and O ranges from 94% to 97% for the hinged and the fixed columns respectively. This ratio is higher than was concluded for single story models which ranged from %50% to %58% in single hinged concrete models and 81%-89% for fixed single storey models. Over all, multi storeies model's ratios are more than single storey models which refers to increment in corner column reaction in multi-storey building under thermal loads effects. the ratios of multi storeies models to single storeies is not proportional to storeies number, for fixed models, this ratio varied from 150% to 180% for both heights while hinged model's reactions ratios of multi-storeies to single storey are around 10 times for models with 3m column height and reduced to around 4 times for models with 6m columns height. thermal reaction forces related to fixed column supports with 6m height are 4 times greater than those of hinged supports with same columns height. This ratio reduced to around 2 for models with 3m columns height.

Finite element models showed that this ratio will increase slightly with the slab length reduction. It is increased from 3.8 for slab length 200m to 4.25 for models with 50m slab length and column height 6m, this increment is observed too for 3m columns height models whereas it increased from 1.96 for slab with length 100m to 2.15 for the slab with 50m length. These results confirm the importance of analysing thermal loads fluctuation at columns reactions for multi storeies buildings whereas the reactions of multi storeies cannot be predicted from single storey analysis and the foundations are subjected to high horizontal reactions which has major impact at foundation size. A comparison study between Etabs finite elements models for existing parking building and the tests results of Aboumoussa and Iskandar (2012) of experiment study for thermal response of same existing building within period of 4.5 years are generated, the range of displacements at south side of the building are close to the allowed limit h/180=2750/180=15.27mm. This side deformations are the critical with direct impact at expansion joint location. The used methods presented different values of displacements. It is clear that the displacement of time-dependent ETABS model with 4.5 years period is very close to test results with 1mm approximately difference, while non-time-dependent properties models results are lesser than tested results within 4.5 Years, so N.T.D. P. don't represent the deformations of all span life of the building since it is even lesser than imposed displacement within 4.5 years. The predicted deformations within 70 years are about 17.5mm, they exceeded the allowed limit 15.27mm. It is clear that the expansion joint location is not within code requirements CEB-FIP for 70 years period, it can be categorized as a reason for observed cracks within this building during its service life.

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