AI Analysis of the Thermal Effects on Reinforced Concrete Buildings with Floating Columns

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ABSTRACT

This study investigates the significant structural difficulties caused by the combined influence of floating columns and thermal stresses on Reinforced Concrete (RC) structures in Saudi Arabia. Discontinuities in load flows are created by floating columns, resulting in increased stress concentrations. These stresses are increased by thermal expansion and contraction caused by temperature fluctuations, which can potentially lead to critical structural deformations. This study evaluates structural performance under different temperature conditions using numerical simulations and AI-driven prediction analysis. The findings highlight the importance of incorporating thermal load considerations and accounting for the effects of floating columns in design methods to guarantee the safety, durability, and long-term stability of reinforced concrete buildings in severe climates for long-span structures. This study emphasizes the integration of AI and simulation methods into structural engineering to support building design and performance when subjected to both heat and load impacts.

Keywords-thermal load; artificial intelligence; structural integrity; floating columns; predictive analysis

I. INTRODUCTION

Reinforced Concrete (RC) structures are widely used in contemporary construction due to their durability and ability to withstand considerable loads. Thermal impacts on RC structures in regions with significant temperature variations, such as Saudi Arabia, play a crucial role in determining their structural integrity and performance. Temperature variations cause concrete and steel to expand and contract differently, resulting in thermal stresses. These stresses can lead to cracking, loss of prestress in prestressed concrete, and overall structural deterioration if not properly considered in the design process [1, 2]. The use of floating columns, although providing architectural flexibility and open space, introduces further complexity. These columns transmit loads to beams instead of the foundation, which can be particularly challenging in seismic and dynamic conditions [3, 4]. The presence of thermal loads increases the stress on structures, particularly in areas such as the Arabian Gulf, where high temperatures can affect the bond strength between the concrete and the reinforcement. This, in turn, negatively affects structural integrity when subjected to service loads [1, 5-9]. The utilization of advanced finite element modeling, along with Artificial Intelligence (AI), has played a crucial role in analyzing these impacts. AI approaches, such as machine learning and neural networks, improve the effectiveness of Structural Health Monitoring (SHM), design optimization, and predictive maintenance. These strategies are crucial for dealing with the complex thermal effects on RC buildings with floating columns [11-17].

AI solutions utilize real-time data from Internet of Things (IoT) sensors to evaluate conditions and predict possible problems, allowing proactive maintenance and guaranteeing long-term structural safety [17-22]. This study investigates the impact of floating columns on the rigidity and durability of RC structures in Saudi Arabia, evaluates the effects of temperature changes on design loads, and utilizes AI tools to predict the structural integrity of buildings under different thermal circumstances. The aim is to enhance design processes and increase the structural resilience of RC structures with floating columns by analyzing the structural performance caused by temperature changes.

II. MODELS' SPECIFICATIONS

The effect of thermal loads and floating columns was studied in eight different models, with and without floating columns and with and without thermal stresses. The results were compared for Displacement, Drift, Base Shear, and Column Forces.

TABLE I. MODELS' DESCRIPTION

No.	Model Name	Model specifications		
		Support type	Floating column	Temperature
1	Model-1	Fixed	yes	20°C
2	Model-2	Fixed	yes	30°C
3	Model-3	Fixed	yes	50°C
4	Model-4	Fixed	yes	-
5	Model-5	Fixed	No	20°C
6	Model-6	Fixed	No	30°C
7	Model-7	Fixed	No	50°C
8	Model-8	Fixed	No	-

III. DESIGN LOADS

The multistory building was designed following the Saudi codes for concrete structures. Loads are defined following SBC 301 for live and dead loads for the specific application and occupancy. The seismic loads are defined using the Static Equivalent Method (SEM) and the Response Spectrum Method (RSE) following SBC 304. Both are standard techniques for seismic analysis. SEM is a simpler technique for low to moderate seismic zones, while RSM takes into account the structure's dynamic reaction to various frequencies of ground motion, ensuring safety and dependability [21, 22].

A. Dead Loads

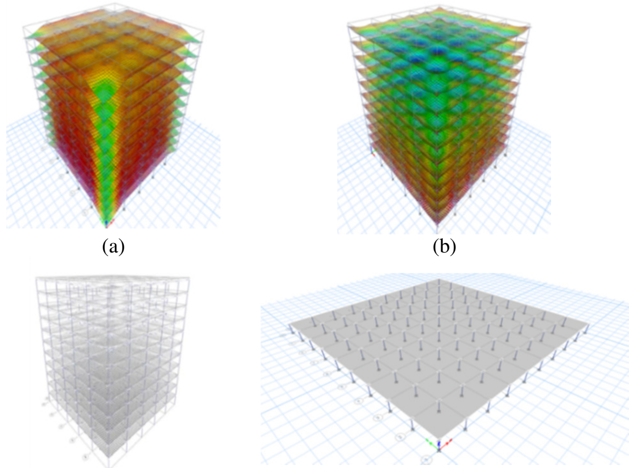
- Self-weight for concrete with a density of 24 kN/m^3.
- Superimposed deadloads for the residential and commercial occupancy of 2 kN/m^2.
- Superimposed load of the helicopter pad of 1.2 kN/m^2.

B. Live Loads

- Service live load of floor slabs of 3 kN/m^2.
- Service live load of staircases of 5 kN/m^2.

C. Seismic Loads

- Spectral response acceleration SDS = 0.254.
- Spectral response acceleration $SD1$ = 0.073.
- Transition period = 4.
- Site class: B.
- Seismic occupancy importance factor, I = 1.25.
- Response modification factor(s), R =4.
- System overstrength factor: 2.5.



(c) (d)

Fig. 1. ETABS software models: (a) with floating column, (b) without floating column, (c) short-span structure (5×6 m), (d) long-span structures (10×10 m).

IV. MODEL ANALYSIS RESULTS

A. Joint Displacement Comparison

Table II displays the joint displacements for the short-span structures, indicating that the maximum displacement is 21.443 mm in story 11 of the models with fixed support, floating columns, and uniform temperatures of 20, 30, and 50°C without thermal effects. Conversely, the minimum displacement is 1.083 mm in story 1 of the models with fixed support, no floating columns, and uniform temperatures of 20, 30, and 50°C, also without thermal effects.

B. Base Shear Comparison

As shown in Table III, the highest Base Shear value of 917.5095 KN is observed in short-span models with fixed support, without floating columns, and uniform temperatures of 20, 30, and 50°C without thermal effects. On the other hand, the smallest Base Shear value of 917.244 KN is observed in models with fixed support, floating columns, and uniform temperatures of 20, 30, and 50°C without thermal effects.

C. Story Drifts

Table IV shows the Drift values for the models of the short-span structure, indicating that the highest Frift value is 0.001787 mm in story 3. This is observed in models with fixed support, floating columns, and uniform temperatures of 20, 30, and 50°C without any thermal effects. The smallest drift value is 0.000382 mm in story 11. This is observed in models with fixed support, no floating columns, and uniform temperatures of 20, 30, and 50°C, without any thermal effects.

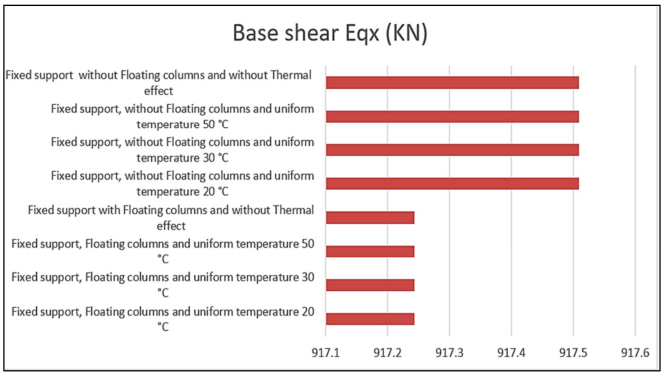


Fig. 2. Comparison of base shear in the x-direction.

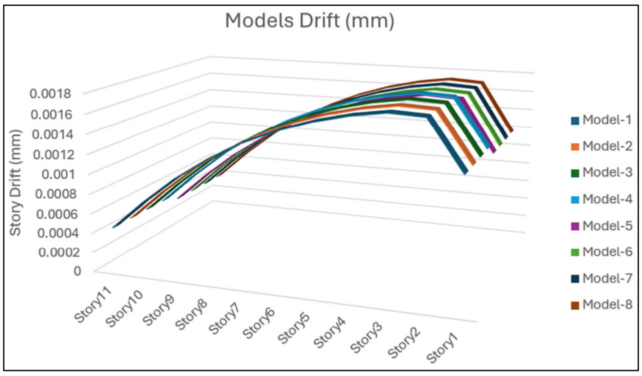


Fig. 3. Story drifts in the x-direction.

TABLE II. MAXIMUM STOREY DISPLACEMENT IN X–DIRECTION

Story	**Case**	**Model-1**	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**	**Model-8**
		Joint displacement (mm)							
Story11	EQx	21.443	21.443	21.443	21.443	19.801	19.801	19.801	19.801
Story10	EQx	20.577	20.577	20.577	20.577	19.08	19.08	19.08	19.08
Story9	EQx	19.347	19.347	19.347	19.347	17.994	17.994	17.994	17.994
Story8	EQx	17.746	17.746	17.746	17.746	16.538	16.538	16.538	16.538
Story7	EQx	15.819	15.819	15.819	15.819	14.758	14.758	14.758	14.758
Story6	EQx	13.627	13.627	13.627	13.627	12.714	12.714	12.714	12.714
Story5	EQx	11.229	11.229	11.229	11.229	10.466	10.466	10.466	10.466
Story4	EQx	8.686	8.686	8.686	8.686	8.074	8.074	8.074	8.074
Story3	EQx	6.068	6.068	6.068	6.068	5.612	5.612	5.612	5.612
Story2	EQx	3.488	3.488	3.488	3.488	3.194	3.194	3.194	3.194
Story1	EQx	1.196	1.196	1.196	1.196	1.083	1.083	1.083	1.083

TABLE III. VALUES OF BASE SHEAR IN X-DIRECTION

Case	**Model-1**	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**	**Model-8**
Eqx	917.244 KN	917.244 KN	917.244 KN	917.244 KN	917.509 KN	917.5095 KN	917.509 KN	917.509 KN

TABLE IV. STOREY DRIFTS FOR THE MODELS IN THE Y-DIRECTION

Story	**Model-1**	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**	**Model-7**	**Model-8**
	Story Drift (mm)							
Story11	0.000447	0.000447	0.000447	0.000447	0.000382	0.000382	0.000382	0.000382
Story10	0.000741	0.000741	0.000741	0.000741	0.000678	0.000678	0.000678	0.000678
Story9	0.001006	0.001006	0.001006	0.001006	0.000941	0.000941	0.000941	0.000941
Story8	0.001226	0.001226	0.001226	0.001226	0.00116	0.00116	0.00116	0.00116
Story7	0.001405	0.001405	0.001405	0.001405	0.001338	0.001338	0.001338	0.001338
Story6	0.001547	0.001547	0.001547	0.001547	0.001479	0.001479	0.001479	0.001479
Story5	0.001656	0.001656	0.001656	0.001656	0.001587	0.001587	0.001587	0.001587
Story4	0.001736	0.001736	0.001736	0.001736	0.001665	0.001665	0.001665	0.001665
Story3	0.001787	0.001787	0.001787	0.001787	0.001714	0.001714	0.001714	0.001714
Story2	0.001771	0.001771	0.001771	0.001771	0.001693	0.001693	0.001693	0.001693
Story1	0.00129	0.00129	0.00129	0.00129	0.001173	0.001173	0.001173	0.001173

TABLE V. SHORT-SPAN COLUMN STRAINING ACTIONS

Model	**Column**	**P**	**V3**	**M2**
		kN	**kN**	**kN.m**
Fixed support, floating columns, uniform temperature 20°C	C5	181.6328	26.6558	85.9037
Fixed support, floating columns, uniform temperature 30°C	C5	181.6328	26.6558	85.9037
Fixed support, floating columns, uniform temperature 50°C	C5	181.6328	26.6558	85.9037
Fixed support, floating columns, without thermal effect	C5	181.6328	26.6558	85.9037
Fixed support, without floating columns, uniform temperature 20°C	C5	123.1983	23.5094	77.178
Fixed support, without floating columns, uniform temperature 30°C	C5	123.1983	23.5094	77.178
Fixed support, without floating columns, uniform temperature 50°C	C5	123.1983	23.5094	77.178
Fixed support, without floating columns, without thermal effect	C5	123.1983	23.5094	77.178

D. Column Forces

Table V displays the forces acting on the short-span model columns. The highest values for Normal Force, Shear Force, and Moment are 181.6328 KN, 26.6558 KN, and 85.9037 KN.m, respectively. These values correspond to models with fixed support, floating columns, and uniform temperatures of 20, 30, and 50°C without any thermal effects. On the other hand, the smallest values for Normal Force, Shear Force, and Moment are 123.1983 KN, 23.5094 KN, and 77.178 KN.m, respectively. These values correspond to models with fixed support, no floating columns, and uniform temperatures of 20, 30, and 50°C, also without any thermal effects.

E. Short and Long-Span Structure Analysis

The impact of thermal loads and floating columns on RC structures varies greatly between long- and short-span structures. Thermal loads cause long-span buildings to expand and compress considerably. This can result in stress and structural deformation. Increased surface area and longer spans for thermal expansion cause significant bending and stress concentrations. The study shows that the thermal load effect on long-span constructions requires strengthened sections and thorough thermal analysis for safety and durability. Shorter span constructions are less sensitive to temperature. Due to their smaller size, they can accommodate thermal expansion and contraction, causing slight stress changes. Therefore, short-span structure thermal load design standards are usually less strict. However, floating columns disrupt load distribution, necessitating careful consideration to manage strains and maintain structural integrity. The comparison indicates that floating columns affect both long- and short-span structures. Thermal loads cause additional challenges for long-span constructions. Effective design and analysis procedures are needed to ensure the stability and durability of structures under various temperature conditions.

TABLE VI. LONG-SPAN COLUMN STRAINING ACTIONS

Story	Column	Output case	P	V3	M2
			kN	kN	kN.m
Story1	C1	Temp+	27.6988	59.8751	141.598

F. Development of an AI Tool for Predicting Structural Integrity

The use of AI in civil engineering has enabled substantial progress in the predictive study of structural integrity. This study developed an AI tool that uses machine learning methods to predict the structural integrity of RC buildings that include floating columns and thermal loads. The tool predicts potential failures or structural concerns by taking into account different constraints and temperature conditions, using data from ETABS simulations. The provided data include the dimensions of the columns, the loads acting on the columns, the shear forces, torsion moments, bending moments, and thermal loads.

1) Data Collection and Preprocessing

a) Data Sources

ETABS software was used to generate intricate 3D models of RC structures, resulting in a comprehensive dataset that included both structural parameters and thermal loads, which accurately represented the environmental effects to reflect realistic environmental impacts.

b) Dataset Parameters

The model takes into account the following features:

- Width of the column (cm)
- Length of the column (cm)
- Axial loads (P, kN)
- Shear Forces (V2, V3)
- Torsion moments (KN.m).
- Bending Moments (M2, M3,)
- Temperature.

c) Data Preprocessing

- Normalization: The dataset was normalized using the standard scaler technique to ensure uniformity and improve the efficiency of machine learning techniques. Normalization is the process of rescaling numerical values to a standardized range, usually ranging from 0 to 1.
- Feature Selection: This process selects a subset of relevant features from a larger set of available features. It involves identifying the most informative and discriminative features that contribute the most to the predictive power of a model. The AI models were improved by selecting key engineering aspects that have a significant impact on structural integrity.

2) Development of Machine Learning Model

The Random Forest (RF) classifier was chosen because of its resilience and exceptional forecast precision. This model was selected after evaluating several machine learning techniques, such as Support Vector Machine and Gradient Boosting. 80% of the data collected were used to train the model. The training involved the identification of patterns and correlations between the input data, which included structural and thermal parameters, and the dependent variable, which was the measure of structural integrity. 20% of the collected data were used to evaluate the performance and accuracy of the model, measuring its ability to generalize to new and unseen data. Cross-validation methods were used to ensure the model's resilience and capacity to apply to new data. The hyperparameters of RF were optimized using grid search and cross-validation to improve the performance of the model. The evaluation and selection of the best-performing model were based on metrics such as Mean Squared Error (MSE), R-squared (R^2), and accuracy.

An AI tool was created to predict the structural integrity of RC structures using input data, such as column measurements, loads, and temperature conditions, via an intuitive interface. The interface enables engineers to enter precise parameters and get immediate predictions on likely failure detects and stress concentrations inside the RC structure. Predictions assist engineers in identifying susceptible regions and implementing proactive actions to strengthen and maintain structural performance. The model used the RF classifier to examine the input data, suitably normalize them using the standard scaler, and provide predictions on the structural condition.

Fig. 4. AI tool before and after submitting ETABS data.

V. CONCLUSIONS

This study investigated the impact of floating columns and thermal loads on the integrity of RC structures in Saudi Arabia. Eight models, with and without floating columns, were examined at various temperature settings (20, 30, 50°C, and without thermal effects), to provide a comprehensive understanding of the implications for structural design and safety. The combination of floating columns and thermal effects is a particularly challenging situation. In structures with both floating columns and long-span structural elements, the combined effects can cause a large increase in design loads. The existence of floating columns results in increased strains due to load path discontinuities. When these structures are subjected to severe temperature loads, strains and deformations can become aggravated. This combination can have a significant impact on structural integrity, requiring more reinforcement and increasing design costs. The developed AI tool provides engineers with a user-friendly interface to provide exact data and obtain instant insights into potential structural integrity issues, allowing them to take proactive steps to improve safety and durability. This AI-based technology predicts the integrity of reinforced concrete structures at a variety of temperatures and can also support effective and environmentally friendly urban growth.

VI. POSSIBLE FUTURE RESEARCH DIRECTIONS

Considering the current findings and the dynamic nature of structural engineering, the following domains have been identified as prospective areas for further research:

- Use advanced simulation and modeling methods to precisely predict the durability of structures when subjected to the combined effect of temperature and load factors.
- Implement regular monitoring systems for long-span constructions with floating columns to effectively detect and deal with thermal issues.
- Consider using different materials with lower coefficients of thermal expansion or greater thermal resistance for critical structural elements.

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