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Thermal Effects on Fatigue Life of RC T-Beam Including other Aspects – A Critical Study.

Himanshu S. Panda[1], Upasana Mishra[2], Pravat Kumar Parhi[3]
[1]*Associate professor, School of Architecture and Planning, KIIT Deemed to be University, Bhubaneswar-24, Odisha, India*
[2]*M. Tech Student, Department of Civil Engineering, College of Engineering and Technology, Bhubaneswar, Odisha-751003, India*
[3]*Professor, Department of Civil Engineering, College of Engineering and Technology, Bhubaneswar, Odisha-751003, India*

Abstract: The concrete material is the most widely used building material in current projects and structures made of it undergo deformation due to a number of loads. Fatigue is one such phenomenon which is a process of progressive, permanent structural change occurring in a material which is subjected to conditions that produce time fluctuating stresses and strains; the structural changes may culminate in cracks or complete fracture after a sufficient number of fluctuations. Fatigue failure is characterized by a fracture in a local area of a structure which is subjected to varying cyclic loading. This loading can be caused by traffic, wind, ocean waves or likewise. The fatigue life of a reinforced concrete structure depends much on the material, stress level and the environmental factors that are considered. The purpose of this study is to analyse the various parameters affecting fatigue in a reinforced concrete T beam. This is done by performing analytical studies on reinforced concrete beam and evaluating the results using ANSYS 18.2 software. Analytical studies regarding the variation of fatigue life, damage, safety factor, equivalent stress and total deformation with magnitude of load, temperature, span length and percentage of main reinforcement of a reinforced concrete T beam are performed using the software. The outcome of the results are plotted and it is observed that fatigue life and safety factor decreases and damage, equivalent stress and total deformation increases with the increase in magnitude of load, temperature, span length of a reinforced concrete T beam. The increase in the percentage of main reinforcement increases fatigue life and safety factor and decreases damage, equivalent stress and total deformation.
Keywords: Fatigue, Load, Temperature, Span length, T beam.

I. INTRODUCTION

A structure is subjected to a lot of stress during its lifetime and as structural design and analysis become more refined and construction practices increase in efficiency, there is an increased need for fundamental information on the behavior of concrete under loads other than static. Particularly there is a demand for more knowledge and understanding of concrete fatigue, which refers to the phenomenon of rupture under repeated loadings each of which is smaller than a single static load that exceeds the strength of the material. Fatigue is exhibited when a material fails under stress applied by direct tension or compression, torsion, bending or a combination of these actions. Since reinforced concrete is a composite material, a structure built in reinforced concrete can fail from fatigue due to several factors. The structural changes may culminate in cracks or complete fracture after a sufficient number of fluctuations. When a structure fails due to fatigue loading, the structure has reached its fatigue life. There are two types of fatigue loading that can result in different failure characteristics. They are called Low-cycle fatigue and High-cycle fatigue. Low-cycle fatigue means that the load is applied at high stress levels for a relatively low number of cycles, while the High-cycles fatigue corresponds to a large number cycles at lower stresses.

in concrete reduces the load carrying capacity and accelerates the deterioration, which in turn shortens the service life of concrete structures. In order to refurbish the performance of the structure, the main requirement is to carry out the structure's fatigue analysis. Interest in the fatigue of concrete arises because structures such as concrete bridges, offshore elements, concrete structures supporting dynamic machines and concrete pavements are loaded by cyclic forces, which are important for the progress of society. Damages in structures can cause severe effects. The safety and reliability of a structure is one of the key issues encountered in the design of a structure. A critical assessment of the fatigue performance of a structure carrying load is of prime importance. However, due to the inherent environmental and material variations in concrete, a concrete specimen under same experimental conditions may give discrete values in fatigue analysis. The present work focuses on the effect of load, temperature, span length, size of the main reinforcement on fatigue in RC T-beam using ANSYS 18.2 software.

Benard et.al [1] conducted experimental investigations to study the fatigue behavior of reinforced concrete deep beams and observed that in all beams, failure occurred with fracture of the longitudinal reinforcement at the intersection with the major concrete crack. Nagesh and Rao [2] reported experimental investigations on the fatigue behavior of lightly reinforced concrete beams subjected to an overload at different instants of loading and observed that overload at any instant decreases the fatigue life of RC beams by accelerating crack initiation process. Neethu Urs et.al [3] represented a methodology to evaluate the residual strength of concrete beams using the failure theories and assessment of residual life using fatigue life measuring law, i.e. Paris Law and obtained that the three failure theories used give proportionate failure stresses. Li Song and Zhiwu [4] studied fatigue flexural behavior of corroded RC beams strengthened with CFRP sheets and noticed that the fatigue life of strengthened beam is increased but the failure mechanism is same in both strengthened and unstrengthened beam. Haiqian Wang et.al [5] did experimental study on failure mechanism of flexural reinforced concrete beams in fatigue load and revealed fatigue failure mechanism of flexural reinforced concrete beams in fatigue load. Sanjeev et.al [6] observed that service life of a structure has three major phases and increased deterioration rate leads to the early failure of RC structures with the end of third phase of the service life. Changfeng et.al [7] did fatigue reliability analysis on the concrete beams and found that Miner's theory can be used to estimate the mean life of the concrete beams. Murthy et al [8] predicted residual strength using the tension softening models and observed that the predicted residual strength is in good agreement with the corresponding analytical values of the past works. Ray and Kishen [9] studied the mechanical behavior of reinforced concrete members influenced by the action of unknown crack bridging reactions of rebar under cyclic loading and concluded that the structural size is the most sensitive parameter in the fatigue crack propagation. Olsson and Pettersson [10] studied fatigue assessment methods for reinforced concrete bridges in Euro code and design methods for railway bridges and concluded that the Cumulative Damage Method is very sensitive to small adjustments in the sectional design. Sain and Kishen [11] assessed the fracture stability and residual strength of reinforced concrete beams and evaluated the fatigue life of RC beams by combining Paris law and R-curve approach. Ameen and Szymansk [12]

Studied fatigue in plain concrete and methods of analysis and gave a brief review of a number of case histories, influencing factors and an introduction to constitutive modeling. Papakonstantinou et.al [13] analysed reinforced concrete beams strengthened with composites subjected to fatigue loading and noticed that_cyclic loading lead to increase in deflections for both control and strengthened beams, however, the deflections increased are slightly lower for strengthened beams. Zhang et.al [14] presented a semi-analytical method to predict the flexure behavior of concrete and observed that smaller the beam height, longer is the fatigue life. C. G. Papakonstantinou [15] studied fatigue performance of reinforced concrete beams strengthened with glass fibre reinforced polymer composite sheets and observed that the role of the GFRP composite sheet is to increase the strength and stiffness of the beam and thus to reduce the stress in the steel. Barnes and May [16] experimented fatigue performance of concrete beams strengthened with CFRP Plates and concluded that strengthened beams perform better in fatigue. Captain P. J. Heffernan [17] investigated the behavior of CFRP post-strengthened reinforced concrete beams for flexure and indicated that an equivalent strength beam, conventionally reinforced and CFRP strengthened, will have equivalent fatigue life. Bazant and Xu [18] investigated crack growth caused by load repetitions in geometrically similar notched concrete specimens of various sizes and found that the size effect vanishes for small structures, while in terms of the stress intensity factor amplitude, it vanishes for large structures. Balaguru and Saha [19] presented an analytical method to predict the increase in deflection and crack width for concrete beams using ACI-design methodology for static loading.

The literature describing studies that have been conducted on the fatigue analysis of reinforced concrete beams, give information about the factors that affect fatigue without considering the environmental effects, which is considered by the authors in the present study. The knowledge of this is important for the refurbishment of the structures by controlling these factors so that the design life of the structure is met.

II. OBJECTIVES OF THE STUDY

The objective of this study is to find out the dependency of fatigue in a RC T-beam with respect to the variation of magnitude of load, temperature, span length and the percentage of steel reinforcement.

A. To determine the total deformation caused in the beam.
B. To know the amount of equivalent stresses developed in the beam.
C. To estimate the fatigue life, damage and safety factor of the beam.
D. Measures to increase fatigue strength of the beam.

III. RESEARCH METHODOLOGY

In the present study, the effect of magnitude of load, temperature, span length and percentage of main reinforcement are analysed with respect to the fatigue life, damage, safety factor, equivalent stress and total deformation using ANSYS 18.2 software.

A. Validation

Validation of the results of the present investigation has been made with that of the research results of C. G. Papakonstantinou, P. N. Balaguru, M. F. Petrou available in the open literature *"Analysis of reinforced concrete beams strengthened with composites subjected to fatigue loading"* [13]. The validation results obtained are shown in Table I and Fig. 1.

TABLE I
VALIDATION OF RESULTS OBTAINED FROM ANSYS WITH [13]

Sl No.	Applied load (max) KN	Applied load (min) KN	Number of cycles to failure (ANSYS)	Number of cycles to failure [13]	Percentage difference in results
1.	31.2	3.3	2e6	2e6	0
2.	35.6	3.3	2e6	2e6	0
3.	40.0	3.3	651440	650000	0.22
4.	43.6	3.3	278310	275000	1.20
5.	53.4	3.3	155710	155000	0.45
6.	62.3	3.3	81689	80000	2.11

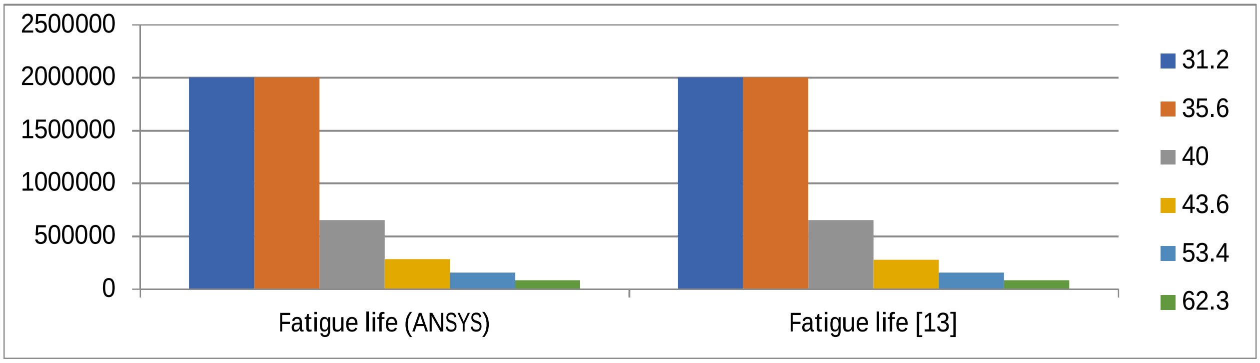

Fig. 1 Variation of fatigue life with the applied load (validation results)

B. Description of the Beam Under Study

The beam considered for the study is a Reinforced concrete T-beam. It has 1600mm span length, 150mm width of web, 300mm width of flange and 350mm overall depth. The effective depth of the beam is kept to 300mm owing to clear cover of 25mm on all sides. The beam is simply supported and four-point bending load application is used. M40 grade of concrete and Fe 415 grade reinforcing steel bars are used. The typical cross-section of the RC T-beam used is shown in the Fig. 2 below.

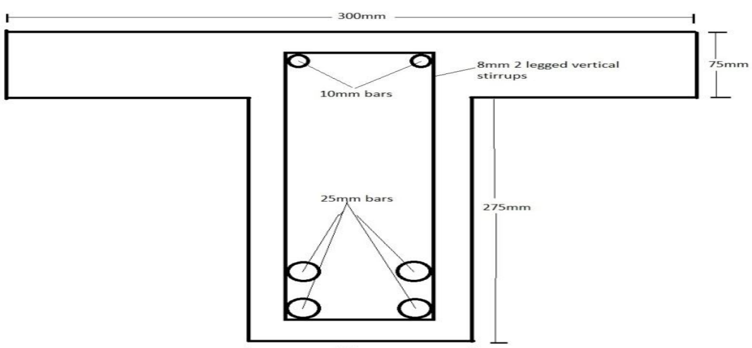

Fig. 2 Typical cross-section of RC T-beam

C. Modeling of The Beam

Modeling of the beam has been done in the Design Modeler of ANSYS Workbench 18.2. The concrete beam and the steel reinforcement are given solid geometry and the stirrups are modeled as line elements. For RC beam, the concrete material for

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concrete and structural steel material for reinforcement and stirrups are selected from the dropdown menu of General Materials, which is already defined in the ANSYS engineering data source library. Their properties are modified according to the requirements. Each part uses its own fatigue material properties and static properties (modulus of elasticity, poisson's ratio, yield strength, coefficient of thermal expansion). Steel plates of dimensions 90mm×15mm are used for load application at the top face of the beam and for supports at the bottom face of the beam. All the elements are bonded to act as a rigid body.

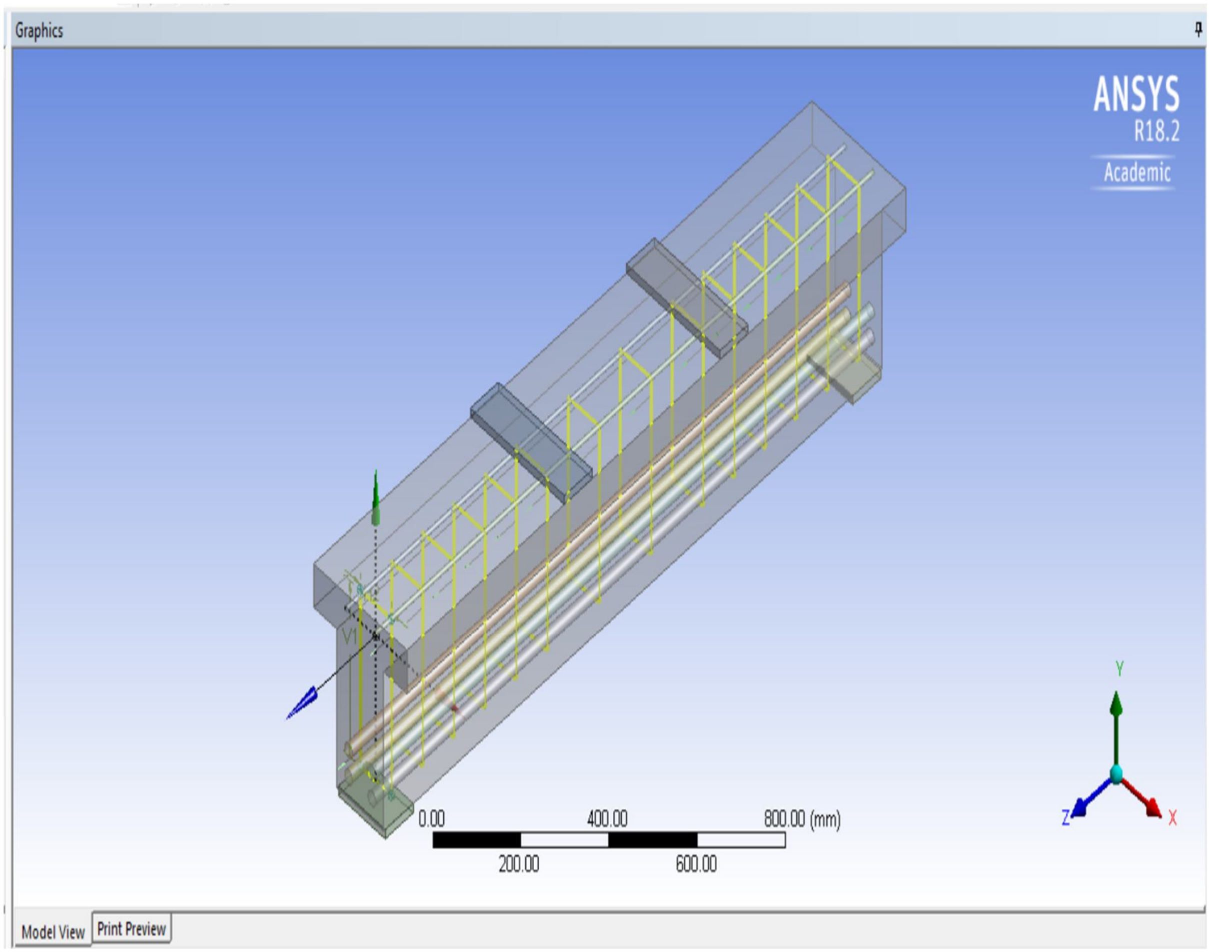

Fig. 3 ANSYS model of the RC T-beam

D. Analysis of the Model

Various parameters affecting fatigue in RC beam, namely magnitude of load, temperature, span length and the percentage of steel reinforcement are analysed using ANSYS Mechanical. The fatigue results can be added before or after a stress solution has been performed. To create fatigue results, the various aspects of a fatigue analysis such as loading type, handling of mean stress effects and more are defined. A graphical representation of the loading and mean stress effects is displayed when a fatigue tool is selected. The constant amplitude proportional loading has been used in this study and the results are obtained for fully reversed loading. Stress life based approach is used for analysis. Results for analysis include fatigue life, damage, safety factor, equivalent stress and total deformation.

IV. RESULTS AND DISCUSSIONS

Results include fatigue life, damage, safety factor, equivalent stress and total deformation. Variation of the above results with magnitude of load, temperature, span length and percentage of main reinforcement are tabulated and plotted to draw conclusions. The results are obtained in ANSYS Mechanical for stress life based analysis of fully reversed loading.

A. Magnitude of Load

The summary of the variation of the fatigue life, damage, safety factor, equivalent stress and total deformation with the magnitude of the load are tabulated in Table II and plotted in Fig 4.

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TABLE II
VARIATION OF THE RESULTS WITH THE MAGNITUDE OF LOAD

Load (KN)	Fatigue life (cycles)	Maximum damage	Minimum damage	Safety factor	Maximum equivalent stress (MPa)	Minimum equivalent stress (MPa)	Total deformation (mm)
100	1000000	1000	500	3.29	27.35	0.02	0.23
300	1000000	1000	500	1.09	82.05	0.06	0.71
500	103350	9676.2	500	0.65	136.75	0.11	1.19
700	30088	33236	500	0.47	191.45	0.15	1.67
900	12382	80763	500	0.36	246.16	0.20	2.15
1100	6521.7	153330	500	0.29	300.86	0.24	2.63
1300	2468.2	405160	500	0.25	355.56	0.29	3.11

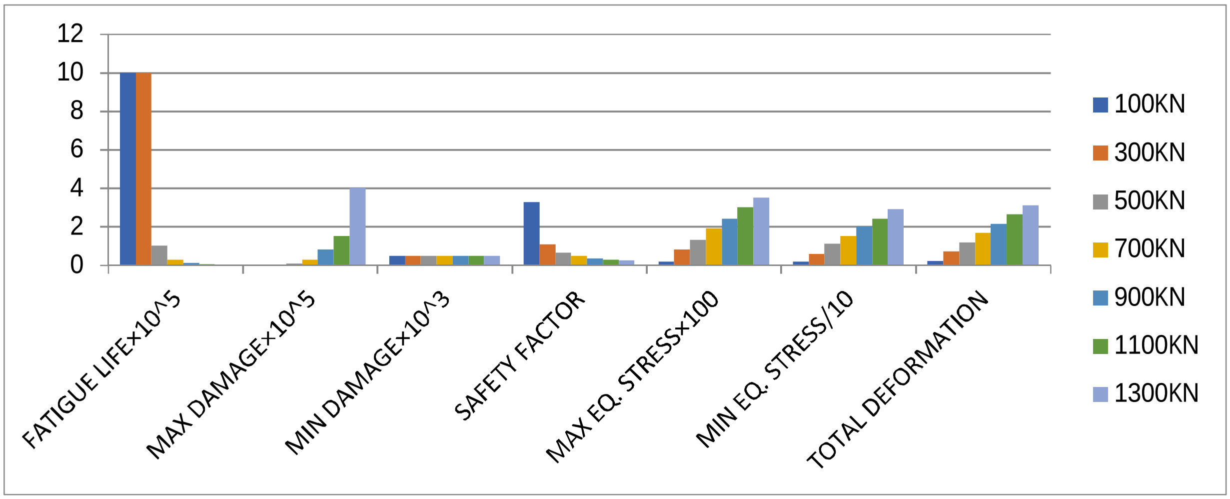

Fig. 4 Variation of the results with the magnitude of load

The results in Table II and Fig. 4 showed that the increase in magnitude of load decreases fatigue life, safety factor and increases damage, equivalent stress and total deformation.

B. Temperature

The summary of the variation of the fatigue life, damage, safety factor, equivalent stress and total deformation with temperature are tabulated in Table III and plotted in Fig. 5.

TABLE III
VARIATION OF THE RESULTS WITH THE TEMPERATURE

Temperature (°C)	Fatigue life (cycles)	Maximum damage	Minimum damage	Safety factor	Maximum equivalent stress (MPa)	Minimum equivalent stress (MPa)	Total deformation (mm)
20	770770	1297.4	1000	0.95	90.18	0.110	0.27
25	404630	2471.4	1000	0.85	100.87	0.091	0.28
30	192530	5193.9	1000	0.74	115.2	0.080	0.30
35	117470	8513	1000	0.65	132.01	0.082	0.39
40	72591	13776	1000	0.57	150.59	0.096	0.48
45	46229	21632	1000	0.50	170.3	0.104	0.58
50	30472	32817	1000	0.45	190.79	0.097	0.67

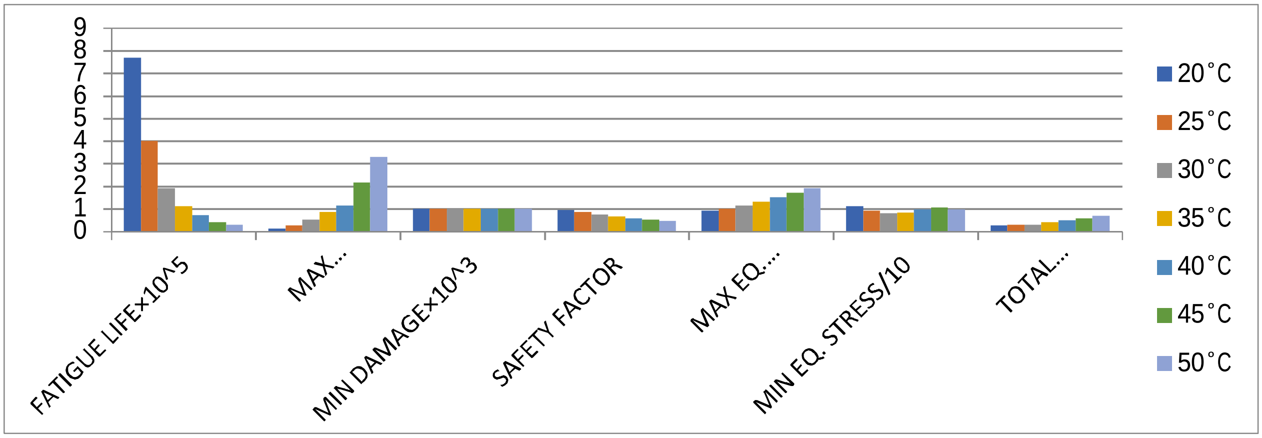

Fig. 5 Variation of the results with the temperature

The results in Table III and Fig. 5 showed that increase in temperature decreases fatigue life, safety factor and increases damage, equivalent stress and total deformation.

C. Span length of beam

The summary of the variation of the fatigue life, damage, safety factor, equivalent stress and total deformation with temperature are tabulated in Table IV and plotted in Fig. 6.

TABLE IV
VARIATION OF THE RESULTS WITH THE SPAN LENGTH OF THE BEAM

Span length (mm)	Fatigue life (cycles)	Maximum damage	Minimum damage	Safety factor	Maximum equivalent stress (MPa)	Minimum equivalent stress (MPa)	Total deformation (mm)
1600	103350	9676.2	500	0.65	136.75	0.112	1.19
1800	48983	20415	500	0.53	167.64	0.091	1.57
2000	27119	36875	500	0.45	196.95	0.071	2.07
2200	16070	62228	500	0.39	228.12	0.060	2.67
2400	7337	136290	500	0.32	273.07	0.054	3.39
2600	3187	313780	500	0.28	313.94	0.049	4.23
2800	1428	700190	500	0.24	364.07	0.030	5.22

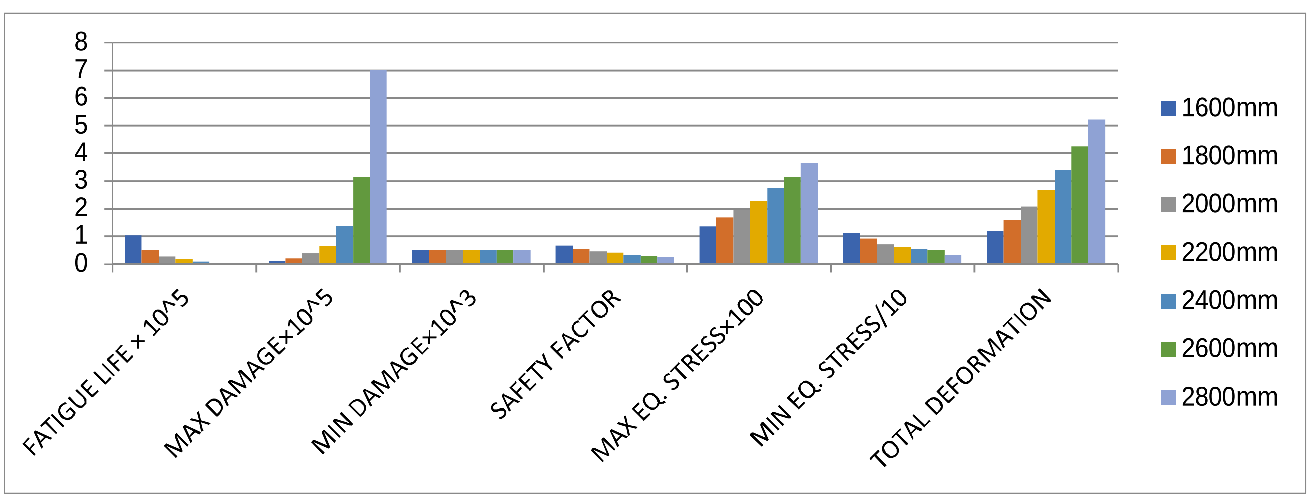

Fig. 6 Variation of the results with the span length of the beam

The results in Table IV and Fig. 6 showed that increase in the span length of the beam decreases fatigue life, safety factor and increases damage, equivalent stress and total deformation.

D. Percentage of Main Reinforcement

The summary of the variation of the fatigue life, damage, safety factor, equivalent stress and total deformation with the percentage of main reinforcement are tabulated in Table V and plotted in Fig. 7.

TABLE V
VARIATION OF THE RESULTS WITH THE PERCENTAGE OF MAIN REINFORCEMENT

% of main reinforcement	Fatigue life (cycles)	Maximum damage	Minimum damage	Safety factor	Maximum equivalent stress (MPa)	Minimum equivalent stress (MPa)	Total deformation (mm)
0.5	27829	35934	500	0.46	195.57	0.168	1.44
1	47782	20928	500	0.53	168.78	0.169	1.40
1.5	61656	16219	500	0.57	157.45	0.135	1.37
2	85072	11755	500	0.61	144.22	0.143	1.32
2.5	96984	10496	500	0.63	140.35	0.174	1.28
3	103270	9683	500	0.65	136.78	0.144	1.26
3.5	133860	7470	500	0.70	127.34	0.111	1.18

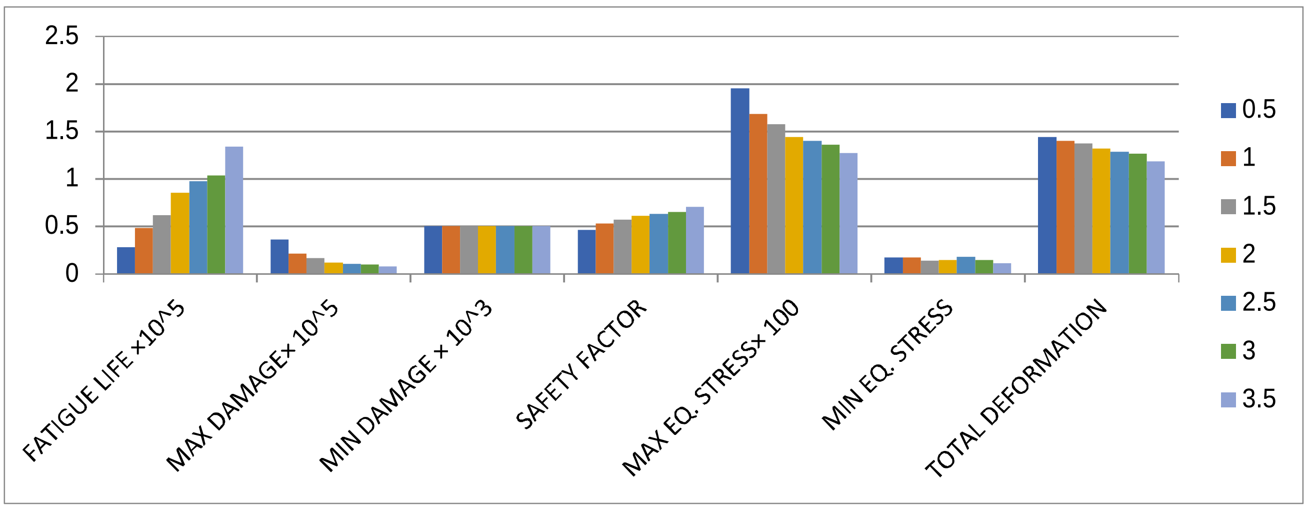

Fig. 7 Variation of the results with the percentage of main reinforcement

The results in Table V and Fig. 7 showed that increase in the percentage of main reinforcement of the beam increases fatigue life, safety factor and decreases damage, equivalent stress and total deformation.

IV. MAJOR CONCLUSIONS

The fatigue analysis in the present study has been carried out for the factors affecting fatigue, namely, magnitude of load, temperature, span length and percentage of main reinforcement of the reinforced concrete T beam. The following conclusions are drawn from the analysis using ANSYS 18.2 software.

A. It is observed that fatigue life decreases with increasing load magnitude, temperature, span length and increases with increasing percentage of main reinforcement. It gives a measure of number of cycles a structure can undergo without failure.

B. It is noticed that damage increases with decreasing fatigue life which in turn decreases the safety factor. The maximum value of safety factor is 15 and values below 1 are regarded as unsafe and failure takes place in these structural parts before the design life is reached.

C. The maximum equivalent stress developed in the beam is inversely proportional to the fatigue life, hence directly proportional to the load magnitude, temperature and span length and inversely proportional to the percentage of main reinforcement.
D. The minimum damage occurred remains constant as the maximum fatigue life available is constant.
E. The minimum equivalent stress doesn't vary much with respect to the fatigue parameters.
F. It is observed that the total deformation developed increases with decreasing fatigue life and affects the hinged end portion more than the roller end support.
G. The analysis of the fatigue results is useful for the refurbishment of the structures, giving an idea to increase the service life of the structure by controlling the parameters related to fatigue damage.
H. In general, avoiding the design details that cause severe stress concentrations or poor stress distribution such as providing gradual changes in sections, eliminating sharp corners and notches, and not using details that create high localized constraints can decrease the effect of fatigue.
I. To reduce the thermal effect on fatigue of the beam, materials resistant to temperature changes should be incorporated.

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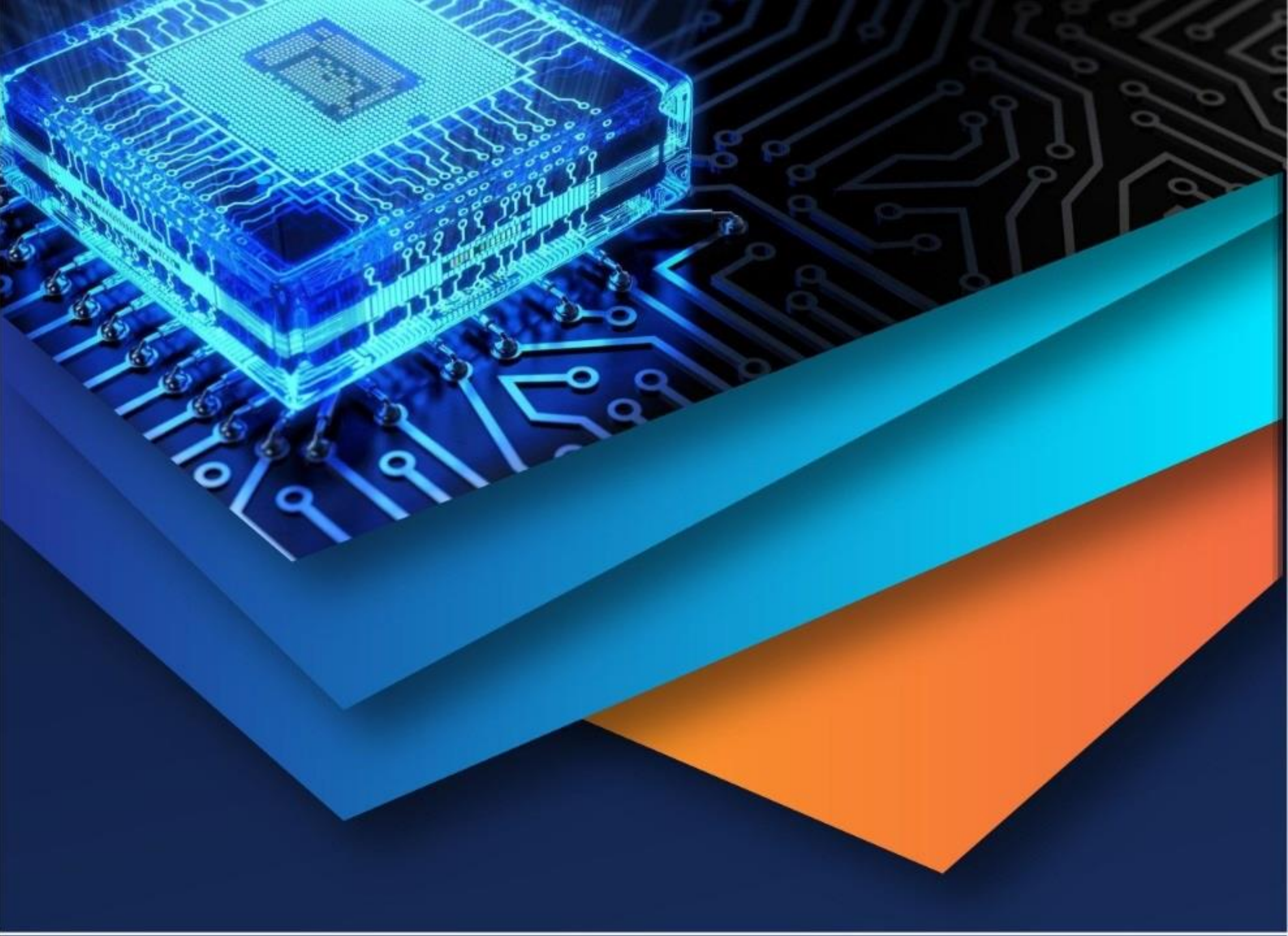

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