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Comparative Study of Seismic analysis of Bridge Substructure in different Seismic Zones as per IRC Guidelines

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***Abstract:** The capacity design philosophy has currently become design norm for the seismic design of structural systems. it is necessary to assess the overstrength capacity of piers before proceeding with the design of the foundation and superstructure. This paper is devoted to developing deterministic procedures for the seismic analysis of substructure and foundation. Therefore, a moment-curvature approach is analysed.*
A parametric study is then conducted to investigate the factors that causes the seismic forces in the system. A simplified analysis methodology is put forward based on IRC SP 114; 2018. It is applicable for seismic design of bridges with a design service life of 100 years, considering Design Basis Earthquake (DBE). It has covered the seismic map and spectral acceleration graphs as specified in IS: 1893-Part-I- 2016. It also adopts the method prescribed for evaluation of liquefaction possibility, as specified in IS: 1893-Part-I- 2016. For the evaluation of seismic forces, Elastic Seismic Acceleration method, Elastic Response Spectrum method and Linear Time History method are specified. The IRC Guidelines describe the various types of special investigations to be carried out for bridges to be constructed in near field zones, skew, and curved bridges and so on. For loads and load combinations, IRC 6-2017 provides the guidelines and specifications. Objective of this code is to provide common procedure for design of bridges. It deals with the various loads such as vehicular loads, braking forces, wind load, water current forces and their combinations.
Keywords: Seismic design of Bridge Substructure, IRC guidelines, Seismic design, Seismic analysis, seismic zones.

I. INTRODUCTION

In order to analyse the behaviour of bridge structures that may be either reinforced or fully or partial prestressed concrete it is essential that analytical model is developed that accurately reflect the true nonlinear dynamic cyclic loading behaviour of those members. This paper contains the scope for applications of guideline, relaxation clauses, general principles of seismic design of bridges, seismic effects on bridge structures, special investigations & studies, and design philosophy for earthquake resistant design of bridges. In the seismic design of bridge structures, there is now a common awareness that excessive strength is neither essential nor desirable for good performance in strong earthquakes.

The emphasis in seismic design has shifted from resistance of large seismic forces to the control of deformations. Hence inelastic structural response (specially for large earthquakes in a multi-level design space) has become the expected norm when designing a structure to resist earthquake forces. It is also well accepted that certain modes of inelastic behaviour are more desirable than others. This is because undesirable behavioural modes may lead to failure, while others provide a controlled ductile response; an essential attribute of maintaining strength while the structure is subjected to reversals of inelastic deformations under seismic response. Therefore, undesirable inelastic deformation modes can be deliberately avoided by amplifying their strength in comparison with those of the desirable inelastic modes.

Thus, for concrete structures, the required shear strength must exceed the required flexural strength to ensure that inelastic shear deformations, associated with large deterioration of stiffness and strength, do not occur. It has also become a norm that seismic design should encourage structural forms that possess ductility. This relates to the careful choice of plastic hinge locations where plastic flexural deformations may occur.

These plastic hinges are designed for high ductility while potentially brittle sections of the structure are designed for a higher strength capacity than those of the plastic hinge sections. These concepts form the basis of the capacity design philosophy currently followed in many seismic design codes.

II. GENERAL PRINCIPLES IN EARTHQUAKE RESISTANT DESIGN OF BRIDGES

1) The bridge must be designed for DBE/MCE utilising a limit state design technique that employs the Force Based Method of seismic design and response reduction factors, as defined in the standards. The Force Based Design have to meet the design philosophy and the principles of capacity design should be followed to protect the structure from collapse.
2) If site-specific spectra are employed, the structure's minimum seismic forces and displacements must not be less than those calculated from the code response spectrum.
3) The longitudinal effect of seismic forces on live loads in bridges is not to be considered. On decreasing live load in transverse direction, the seismic force on live load should be considered.

III.SEISMIC ANALYSIS METHODS

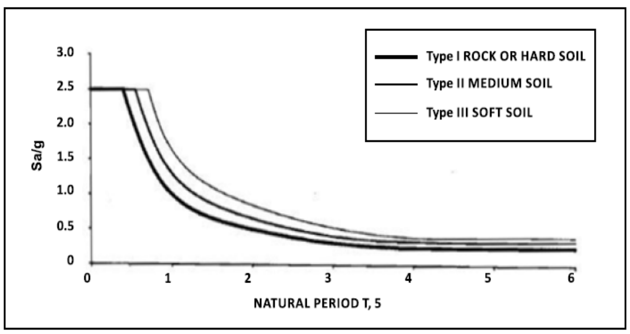
A. Elastic Seismic Acceleration Method (Seismic Coefficient Method)

For the structures having small span with low to medium height, elastic seismic acceleration method is used to calculate the seismic force considering single mode of vibration. The seismic force, F_h is calculated by multiplying dead load and reduced live load with design seismic coefficient, A_h

here, $A_h = (Z/2)(Sa/g)/(R/I)$

Where, Z = zone factor, I = Importance factor, R = Response reduction factor from IRC SP 114 2018 and Sa/g = Design acceleration coefficient for different soil types, normalized with peak ground acceleration, corresponding to natural period T of structure. Time period T may be estimated by, $T = 2.0\sqrt{(D/1000F)}$

Sa/g corresponding to Time period can be calculated from the Figure 1



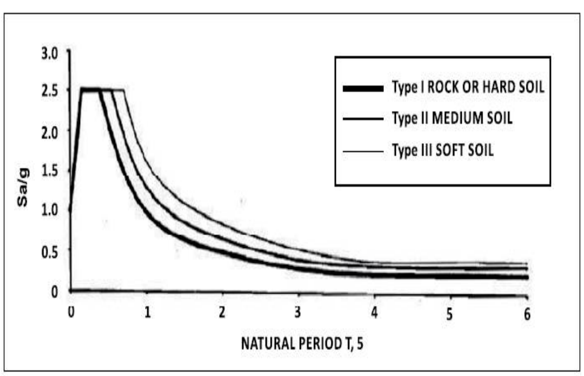
$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil site :} \begin{cases} 2.5 & 0 < T < 0.40\ s \\ 1/T & 0.40\ s < T < 4.00\ s \\ 0.25 & T > 4.00\ s \end{cases} \\ \text{For medium stiff soil sites :} \begin{cases} 2.5 & 0 < T < 0.55\ s \\ 1.36/T & 0.55\ s < T \le 4.00\ s \\ 0.34 & T > 4.00\ s \end{cases} \\ \text{For soft soil sites :} \begin{cases} 2.5 & 0 \le T \le 0.67\ s \\ 1.67/T & 0.67\ s \le T \le 4.00\ s \\ 0.42 & T > 4.00\ s \end{cases} \end{cases}$$

Fig. 1 Spectra for Elastic Seismic Acceleration Method

Where, D = Appropriate dead load and reduced live load and F = Horizontal force required to be applied at centre of mass in transverse direction and at the top of bearing in longitudinal direction to cause 1mm deflection.

B. Elastic Seismic Acceleration Method (Seismic Coefficient Method)

This is a general method, suitable for more complex structural systems for example, continuous bridges, bridges with large difference in pier heights, bridges which are curved in plan, etc. In this method dynamic analysis of the structure is performed to obtain the first as well as higher modes of vibration. The forces are obtained for each mode by use of response spectrum as given in Figure 2



$$\frac{S_a}{g} = \begin{cases} \text{For rocky or hard soil site :} \begin{cases} 1 + 15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.40\ s \\ 1/T & 0.40\ s < T < 4.00\ s \\ 0.25 & T > 4.00\ s \end{cases} \\ \text{For medium stiff soil sites :} \begin{cases} 1 + 15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.55\ s \\ 1.36/T & 0.55\ s < T < 4.00\ s \\ 0.34 & T > 4.00\ s \end{cases} \\ \text{For soft soil sites :} \begin{cases} 1 + 15T & T < 0.10\ s \\ 2.5 & 0.10\ s < T < 0.67\ s \\ 1.67/T & 1.67s < T < 4.00\ s \\ 0.42 & T < 4.00\ s \end{cases} \end{cases}$$

Fig. 2 Spectra for Elastic Response Spectrum Method

The following are the steps concerned in Elastic Response Spectrum methodology

1) Formulation of Associate in Nursing acceptable mathematical model consisting of lumped mass system exploitation 2D/3D beam parts. The mathematical model should represent dynamic characteristic of structure, substructure, foundation and soil/ rock spring. In rock and really stiff soil fastened base is also assumed.
2) Determination of natural frequency and mode shapes following a customary transfer matrix, stiffness matrix, finite part methodology or the other approach.
3) Determination total response by combining responses in numerous modes by mode combination procedure like root of the total of the Squares (SRSS) and calculate the bottom shear values.

This methodology is appropriate for pier height quite thirty m and for Bridges having abrupt or uncommon changes in mass, stiffness or pure mathematics on its span.

C. Time history Method

In bridges wherever pier heights square measure high, bridge has abrupt or uncommon changes in mass, stiffness or pure mathematics on its span and has giant variations in these parameters between adjacent supports, special unstable devices like dampers, isolator shock transmission unit etc square measure provided and wherever the massive spatial variation ought to consider than time history technique should be used. The dynamic analysis of a bridge by time history technique could also be disbursed victimization direct gradual methodology of integration of equations of motion appropriate steps sufficiently small to incorporate response of highest modes of vibration.

IV. ILLUSTRATIVE EXAMPLE

The 2-lane bridge considered with 10m carriageway and 11m overall width. The Bridge span is simply supported resting on POT-PTFE bearings. Superstructure consists of 33m span with 3 no. of PSC girders supporting RCC deck slab. Substructure consists of circular pier of 2m diameter with RCC pier cap of 1.8m depth with pile foundation. For Medium stiff soil site Refer Figure 3. The steps involved

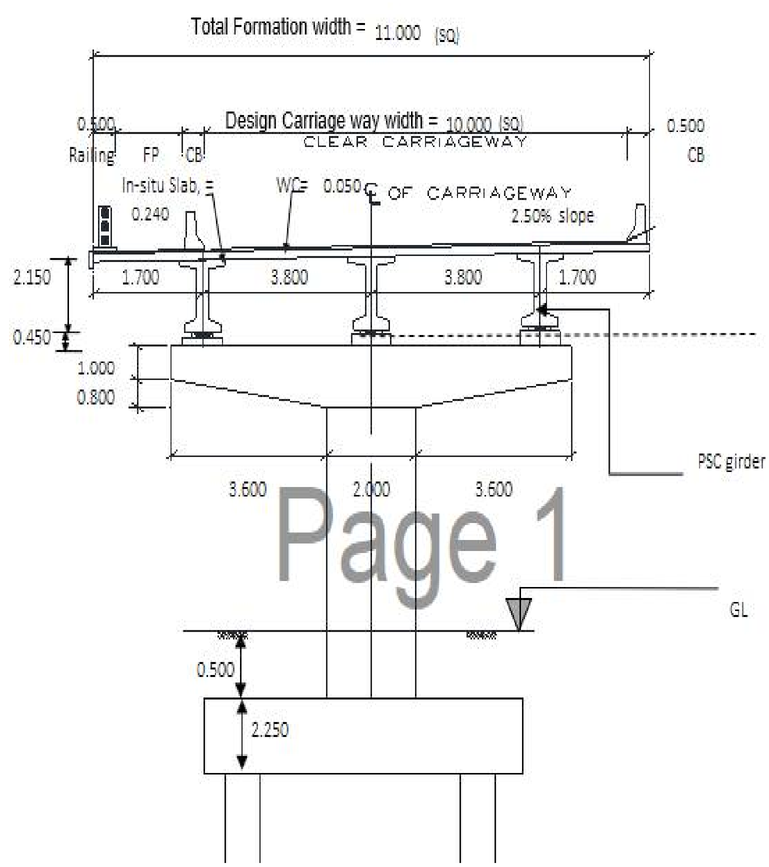


Fig. 3 Sketch of Illustrative example

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A. Load Calculation

1) *Dead load and Super Imposed Dead Load* – Dead load of the superstructure, substructure, and Super imposed dead load i.e, load due to wearing coat and crash barrier and snow at the top of foundation is calculated.
2) *Wind Load* – Wind load on superstructure, substructure and snow is calculated as per IRC:6-2017.
3) *Snow Load* – Depth of snow is considered as 1.8m.
4) *Live Load* – Live load cases considered as per IRC 6;2017. Live load analysis is done in STAAD Pro. Software to get maximum and minimum reactions and moments to the corresponding cases. For this model of unit size is created and loading of vehicles considered as per IRC 6;2017. Maximum reactions and moments are also calculated by considering congestion as per IRC 6;2017.

B. Calculation of Seismic force and design loads at bottom of pier

1) *Seismic Force* – To calculate Time Period model is created in STAAD Pro. Software with unit dimensions and analysed with horizontal load of 1KN to calculate the deflection (Figure 4) and corresponding force required for 1mm deflection is calculated. Horizontal seismic force and moments in longitudinal and transverse direction considering 20% live load are calculated at the top of the foundation. Same process is followed to calculate in snow condition.
2) *Pile Capacity Check* – Factored load in Normal and Congestion are calculated for pile capacity check as per IRC 78;2014.
3) *Design Loads for PIER* – Load factors as per IRC 6;2017 are considered for the calculation of ULS design loads at the bottom of pier.

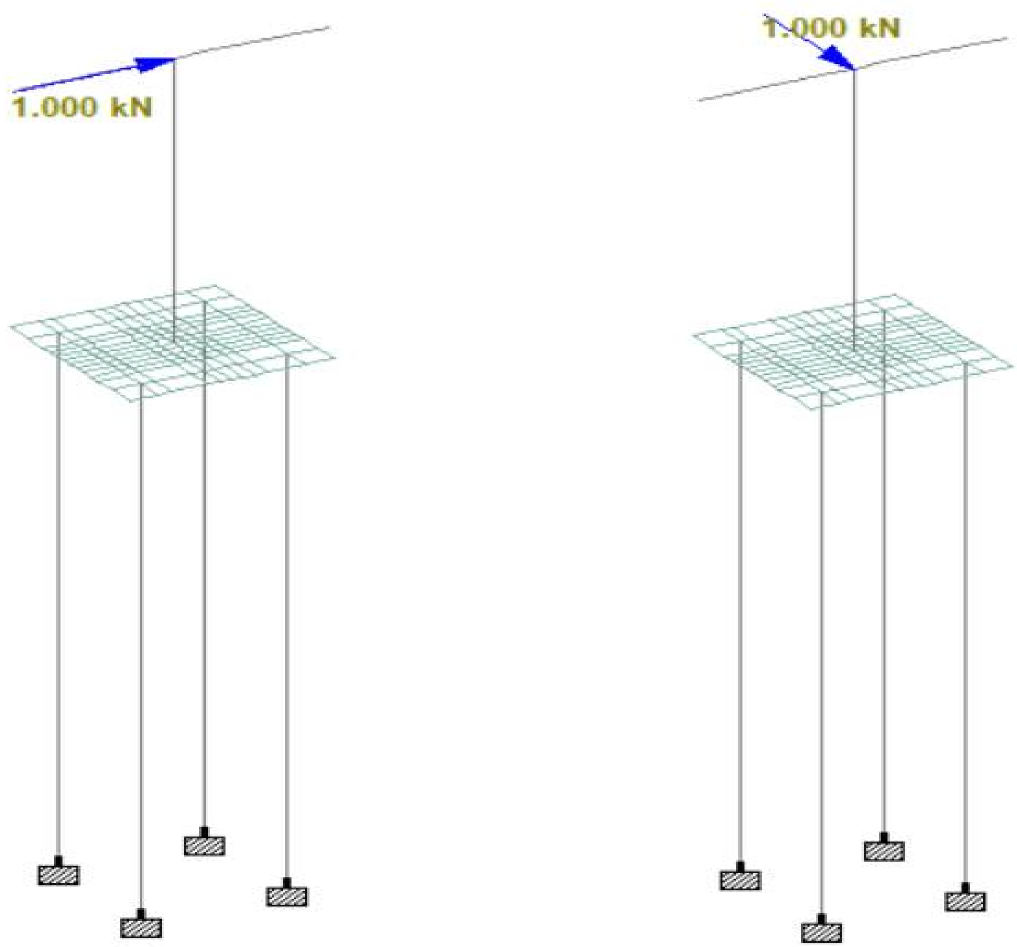

Fig. 4 STAAD Model

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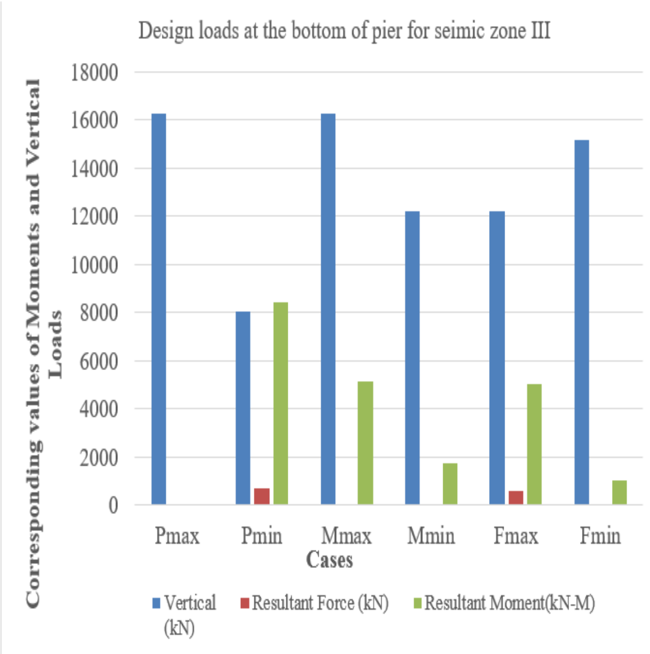
C. Results

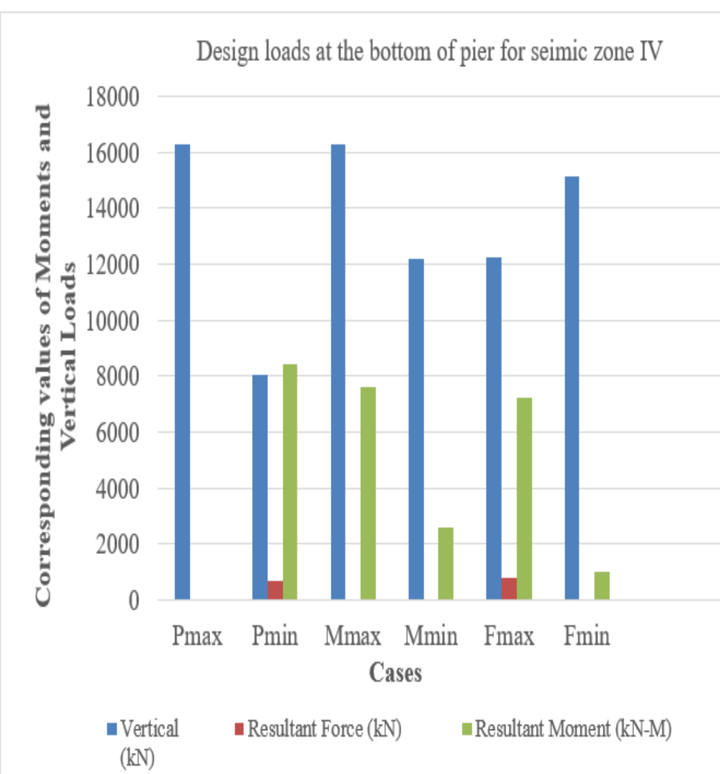
Design loads for same pier in three different seismic zones are:

1) For Seismic Zone III



Case	Corresponding	V (kn)	F (kn)	M (kn-m)
P_{max}	Moment and Force	16274	0.00	0.00
P_{min}	Moment and Force	8058	681	8405
M_{max}	Vertical and Seis. Force	16274	0.00	5115
M_{min}	Vertical and Seis. Force	12183	0.00	1725
F_{max}	Vertical and Moments	12227	554	5015
F_{min}	Vertical and Moments	15171	0.00	1008

2) For Seismic Zone IV



Case	Corresponding	V (kn)	F (kn)	M (kn-m)
P_{max}	Moment and Force	16274	0.00	0.00
P_{min}	Moment and Force	8058	681	8405
M_{max}	Vertical and Seis. Force	16274	0.00	7605
M_{min}	Vertical and Seis. Force	12183	0.00	2613
F_{max}	Vertical and Moments	12276	802	7227
F_{min}	Vertical and Moments	15171	0.00	1008

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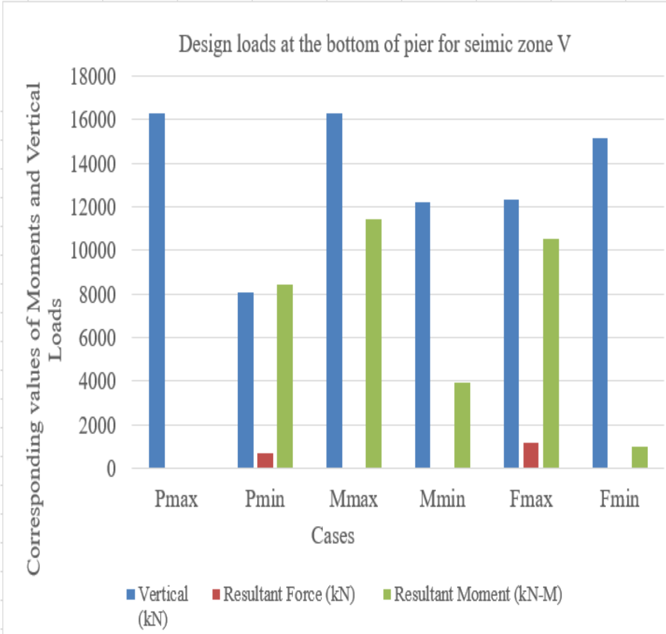
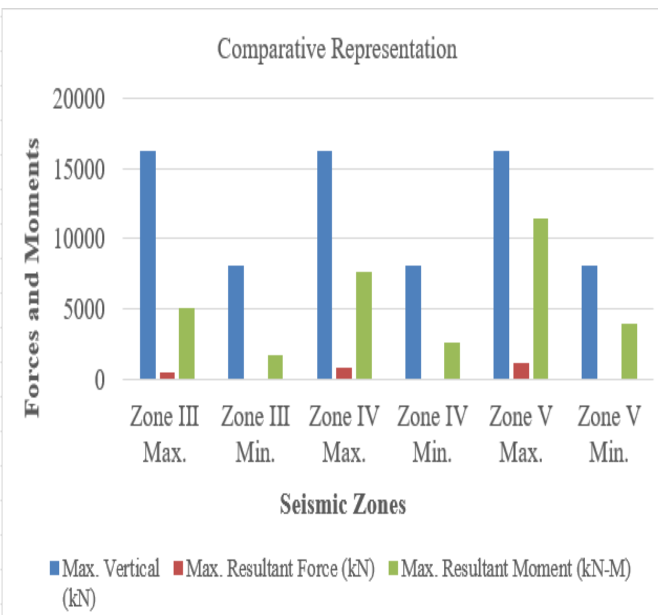
3) For Seismic Zone V



Case	Corresponding	V (kn)	F (kn)	M (kn-m)
P_{max}	Moment and Force	16274	0.00	0.00
P_{min}	Moment and Force	8058	681	8405
M_{max}	Vertical and Seis. Force	16274	0.00	11440
M_{min}	Vertical and Seis. Force	12183	0.00	3946
F_{max}	Vertical and Moments	12348	1175	10546
F_{min}	Vertical and Moments	15171	0.00	1008

4) Comparative graphical representation of maximum forces and moments for different seismic zones is shown below



Seismic Zones	Max. Vertical (kN)	Max. Resultant Force (kN)	Max. Resultant Moment (kN-M)
Zone III Max.	16274	554	5115
Zone III Min.	8058	0.00	1725
Zone IV Max.	16274	802	7605
Zone IV Min.	8058	0.00	2613
Zone V Max.	16274	1175	11439
Zone V Min.	8058	0.00	3946

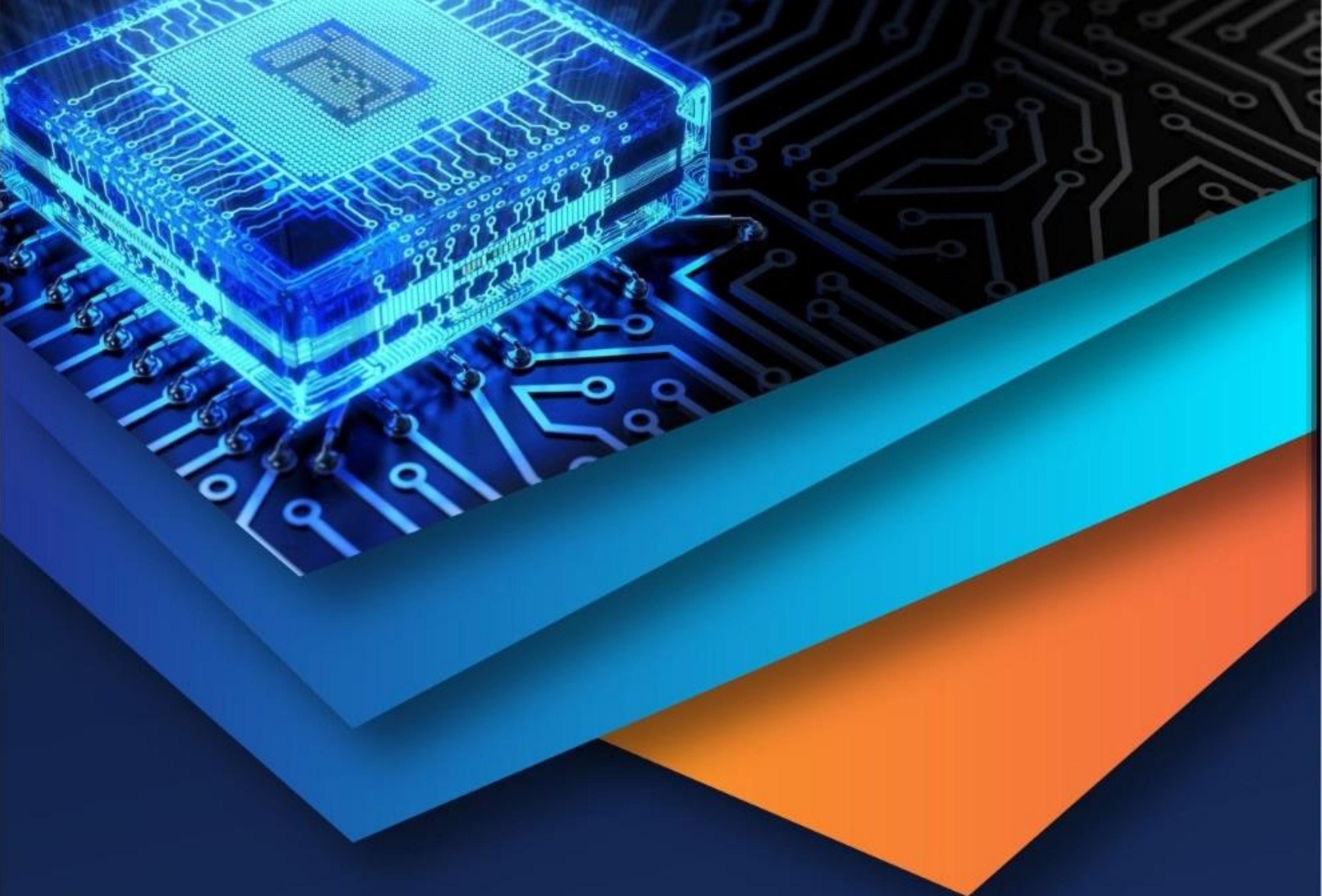
V. CONCLUSION

After the Seismic analysis of same structure for different seismic zones, it is concluded that:

1) The Maximum Resultant force in Zone III is increased by 45% in Zone IV.
2) The Maximum and Minimum Resultant moment in Zone III is increased by 49% and 51% respectively in Zone IV.
3) The Maximum Resultant force in Zone IV is increased by 46.4% in Zone V.
4) The Maximum and Minimum Resultant moment in Zone IV is increased by 50.4% and 51% respectively in Zone V
5) The Maximum Resultant force in Zone III is increased by 112% in Zone V
6) The Maximum and Minimum Resultant moment in Zone III is increased by 123.6% and 128.8% respectively in Zone V.

REFERENCES

[1] John B. Mander, Anindya Dutta and Pankish Goel, “Capacity Design of Bridge Piers and the Analysis of Overstrength.” State University of New York at Buffalo Department of Civil, Structural and Environmental Engineering Buffalo, New York 14260.
[2] Rakhi Kulkarni, Shrabony Adhikary and Yogendra Singh, “Seismic performance of a bridge with tall piers.” Bridge Engineering · November 2014.
[3] Antonius 1, Iswandi Imran 2, “Ductility of confined bridge piers in the seismic region.” 1 Lecturer of Civil Engineering, Universitas Islam Sultan Agung, Indonesia, 2 Professor of Civil Engineering, Institute Teknologi Bandung, Indonesia.
[4] IRC SP:114-2018, “Guidelines for Seismic design of Road Bridges.”
[5] IRC:112-2020, “Code of Practice for Concrete Road Bridges.”.
[6] IRC:6-2017, “Standard Specifications and Code of Practice for Road Bridges, Section II Loads and Load Combinations (Seventh Revision).”
[7] IRC:78-2014, “Standard Specifications and Code of Practice for Road Bridges, Section VII Foundations and Substructure (Revised Edition).”



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