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https://doi.org/10.5109/6792825

出版情報：Evergreen. 10 (2), pp.752-764, 2023-06. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Seismic Performance and Suitability of Elastomeric and POT PTFE Bearings for Girder Bridges

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(Received March 1, 2023; Revised April 30, 2023; accepted May 11, 2023).

Abstract: Bridge bearings perform the dual function of transferring reaction forces from the super-structure to the sub-structure and facilitating the venting of possible extra stresses that may generate due to restrained deformations. In the present study, the seismic performance of the girder bridges has been investigated as per the provision IRC:6-2017, IS:456-2000, IS 1893 Part (III) 2016, and IRC: SP:114-2019. Two types of bearings have been considered in the study, viz. Elastomeric bearing (EB) and POT PTFE bearings. The design and efficiency of bridges are greatly influenced by the type of bearing adopted and the serviceability of bearings. In past studies, the efficacies of the bearings have not been investigated under the different seismic zone of India. The study presented here focused on parameters that may affect the selection of a particular bearing class and attempted to find the optimum range within which a particular bearing could perform better. Parametric studies have been done by varying span length and pier height under India's different seismic zone. The comparison of seismic performances of POT PTFE and Elastomeric bearings was carried out vis-à-vis the variation in span length, seismic zones and pier height. The provisions of IRC:6-2017, IS:456-2000, and IRC: SP:114-2019 were incorporated to analyze seismic variation for medium-span bridges. It was observed that, the POT PTFE bearings are found better as compared to elastomeric bearing by considering span variation, pier height and seismic zone.

Keywords: Bridge bearings; girder bridges; seismic design; Elastomeric bearing; seismic zone

1. Introduction

To mitigate seismic response, elastomeric bearings are the go-to technique for decoupling the bases of buildings and bridges. They allow controlled relative movement between the sub and super-structure, curtailing the extra stresses that tend to generate if the free movement of the super-structure is restricted[1)]. Based on the type of release and the mechanism incorporated to provide the release, bearings may be categorized into different classes like sliding bearings, PoT bearings, elastomeric bearings, roller bearings, rocker & pin bearings, and disc bearings[2)]. The suitability of a specific type depends upon the site specifications and design considerations. Research has been conducted on the performance of different bearings individually to study their field of application[3)]. However, the state-of-the-art lacks a comparative analysis of their field of application. As such, the research intends to present a comparative analysis of the effect of two major types of bearings used in Indian bridges: Elastomeric bearing, which is a flexible bearing, and POT PTFE bearing, a rigid bearing, on the seismic performance of medium span girder bridges.

2. Literature Review

Various studies have been done on bridge bearings; it was focused on understanding the behavior of different types of bearings, exploring different materials for improving their performance, and improving the existing analytical procedures to address their design. Gilstad et al.[4)] presented an experiment-based approach to check the stability criteria for PoT, disc, and spherical bearings. The work aimed at drawing attention to the need to incorporate stability checks in the design of bearings as it not only affected the structural efficiency but also was found to affect the long-term cost of the infrastructure. Gupta et al.[5)] studied the effect of High Damping Rubber bearings on the seismic performance of curved bridges, highlighting that the material selection for bearings is equally important, as is the type of load transfer action of the bearing. Further, they presented a vivid analysis of the variations arising due to the consideration of different classes of seismic loads and the role of the selected bearing in augmenting the structural performance. Sato et al.[6)] incorporated steel bearings and subjected them to strong ground motion conditions to determine the suitability of the material under such extreme events. They carried out seismic hybrid experiments to attain a numerical pin-bearing model to understand the non-linear performance of such bearings for harnessing their full potential in case of earthquake excitations. Wei et al.[7)] attempted to study the effect of friction-based fixed bearings contrary to conventional fixed bearings to determine the suitability of this modified approach in mitigating the disastrous effects of strong ground motions. They described friction-based fixed bearings that behaved and performed as fixed in usual conditions but allowed sliding motion under earthquake excitations, thereby reducing further damages. The results presented a strong case for using such bearings in real life scenarios and highlighted the conditions required to obtain the analytical results on the field. Huth et al.[8)] investigated the influence of parameters such as the lubrication condition, rotation angle, pressure acting on the elastomer pad, and temperature on the restoring moments of the PoT bearings.

Xiaoxing Xu et al.[9)] studied the application of isolation bearings in cold regions. Kazeminezhad et al.[10)] investigated that depending on the degree of rotation lateral displacement limit, the isolator's vertical stiffness could be altered Since elastomers have a high strain-recovery capacity, they are ideally suited for use as base isolators. Using the elastomer's near incompressibility, a composite is formed with reinforcement (often steel or fibers) to improve the bearing's vertical and lateral performance.

Several research have investigated the response of isolated structure under seismic loading.[11-15]

A low-friction material pad derived from polytetrafluoroethylene, also called PTFE (or Teflon). Shreeman et al.[16)] Structures close to causative earthquake faults may exhibit substantially different seismic responses than those recorded from the excitation source.

In the same context, the problem presented here includes a performance comparison of two popular classes of bearings, viz. Elastomeric and POT PTFE bearings, in terms of reaction forces and moments, transferred from the considered girder bridge super-structure to the sub-structure with an aim to understand the influence of bearing type on the transfer. During the course of the study, this performance was tested for variations arising due to alteration of span lengths and the seismic zone considered. The aim was, thus, to identify the relative suitability of the bearings with a view to understanding their behavior for improved real-world applications

3. Bridge Description

Five configurations of slab-on-girder Prestressed Concrete bridges were considered with span lengths of 10m, 20m, 30m, 40m, and 50m. Spans below 10m were not considered as box-type sections perform better in that range. Also, spans above 50m were not considered as for spans more than 50m, Steel Girder & Steel Truss type structures provide better results.

Two-span super-structure with a 12m wide carriageway with a four-girder system was considered with I-section at the mid-span, with haunches at the top and bottom flanges, and a T-shaped section with haunches at the flange at the support section as shown in figure 2. A flaring section was provided to provide continuity. Based on the provisions recommended by IS:456[17)] the preliminary dimensions of girder sections were decided. The initial depth was decided in the range of L/10 to L/15, and based on stress checks carried out by comparing stress ratios in concrete and cables; the sections were suitably modified and ultimately finalized. M45 grade concrete and Fe 500 grade of steel were used. Strands for pre-stressing considered were low relaxation type strands with an ultimate strength of 1860 N/mm^2. Table (1) shows the dimensions for the girder sections for different span lengths. Furthermore, other features of the super-structure have been enlisted in Table (2).

4. Modelling and analysis of the bridge

Two types of bearings have been considered i.e., Elastomeric bearing (EB) and POT PTFE bearing. Response reduction factor (R) and Time period values were taken into consideration based on the type of bearings specified by IRC: SP:114-2019[18)] and IRC6[19] and IS-1893[20-21] accordingly, the effect of bearings in transferring the reaction forces have been considered in the different seismic zones for all the bridge spans. Three response parameters have been considered, viz. Shear force (V), longitudinal moment (ML), and transverse moment (MT) resulting at the pier level, passing through bearings to the sub-structure, were taken as 'characteristic quantities' for comparison.

5. Parametric Study

To determine the relative performance between EB and POT PTFE bearings, different span lengths and different seismic zones have been considered in the analysis. [22-25)] The span lengths have been varied from 10m to 50m

5.1 Variation of Span

Several studies has been done by researchers On varying the span of the bridges[26-27)], the shear force transmitted has increased significantly up to 291% in POT PTFE under the different seismic zone as shown in Fig 3 (a-d). However, the shear force transmitted has increased up to 77% in EBs. The longitudinal moment and Transverse moment have also been increased up to 286% and 322%, respectively, in POT PTFE as shown in figs. 4-5. However, the longitudinal and transverse moment has increased by 76% and 98% for EBs. The variation of shear force is also found to be non-linear for varying spans.

Table 1: Dimensions for the girder sections for different span lengths

10m Span	**Support Section (in mm)**		**Mid-span Section (in mm)**	
	Width (B)	Depth (D)	Width (B)	Depth (D)
Deck slab	3000	220	3000	220
Top flange	600	150	600	150
Top flange Haunch x 2	0	0	155.0	75
Web	600	950	290	700
Bottom Flange Haunch x 2	N/A	N/A	155	100
Bottom flange	N/A	N/A	600	250
Total depth of girder	N/A	1100	N/A	1100
20m Span	Support Section (in mm)		Mid-span Section (in mm)	
	Width (B)	Depth (D)	Width (B)	Depth (D)
Deck slab	3000	220	3000	220
Top flange	650	150	650	150
Top flange Haunch x 2	0	0	180.0	75
Web	650	1300	290	1050
Bottom Flange Haunch x 2	N/A	N/A	180	150
Bottom flange	N/A	N/A	650	250
Total depth of girder	N/A	1450	N/A	1450
30m Span	Support Section (in mm)		Mid-span Section (in mm)	
	Width (B)	Depth (D)	Width (B)	Depth (D)
Deck slab	3000	220	3000	220
Top flange	650	150	650	150
Top flange Haunch x 2	0	0	180	75
Web	650	1750	290	1500
Bottom Flange Haunch x 2	N/A	N/A	180	150
Bottom flange	N/A	N/A	650	250
Total depth of girder	N/A	1900	N/A	1900
40m Span	Support Section (in mm)		Mid-span Section (in mm)	
	Width (B)	Depth (D)	Width (B)	Depth (D)

Deck slab	3000	220	3000	220
Top flange	850	150	850	150
Top flange Haunch x 2	0	0	280	75
Web	850	2250	290	2000
Bottom Flange Haunch x 2	N/A	N/A	280	150
Bottom flange	N/A	N/A	850	250
Total depth of girder	N/A	2400	N/A	2400
50m Span	Support Section (in mm)		Mid-span Section (in mm)	
	Width (B)	Depth (D)	Width (B)	Depth (D)
Deck slab	3000	220	3000	220
Top flange	950	150	950	150
Top flange Haunch x 2	0	0	325	75
Web	950	2650	300	2300
Bottom Flange Haunch x 2	N/A	N/A	325	150
Bottom flange x 2	N/A	N/A	950	350
The total depth of girder	N/A	2800	N/A	2800

Table 2: Super-structure properties common to all spans

S. No.	Attribute	Value	
1	Projection beyond the center line of bearing	0.930	m
2	Expansion gap	0.040	m
3	Total width of super-structure	12.000	m
4	Angle of skew	0	degrees
5	Width of the crash barrier	0.500	m
6	Carriageway width	11.000	m
7	No. of Girders	4	
8	Cantilever at each end of cross-section	1.500	m
9	Spacing of girders	3.000	m

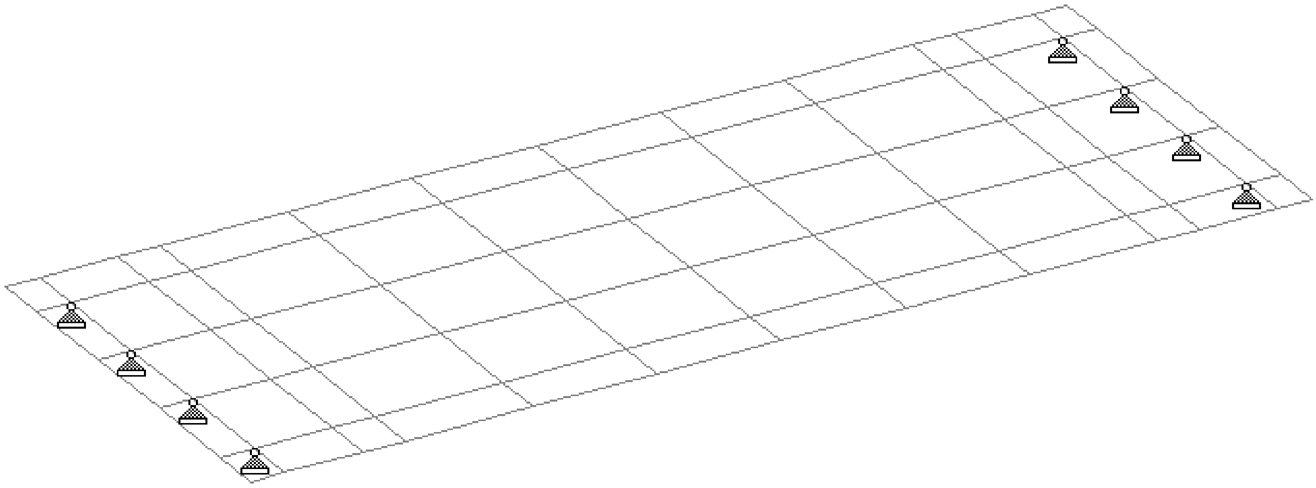

Fig. 1: STAAD.Pro bridge model for 20m span configuration

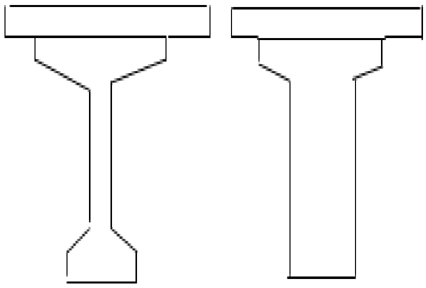

Fig. 2: Girder cross-section at (a) Mid-span and (b) Support

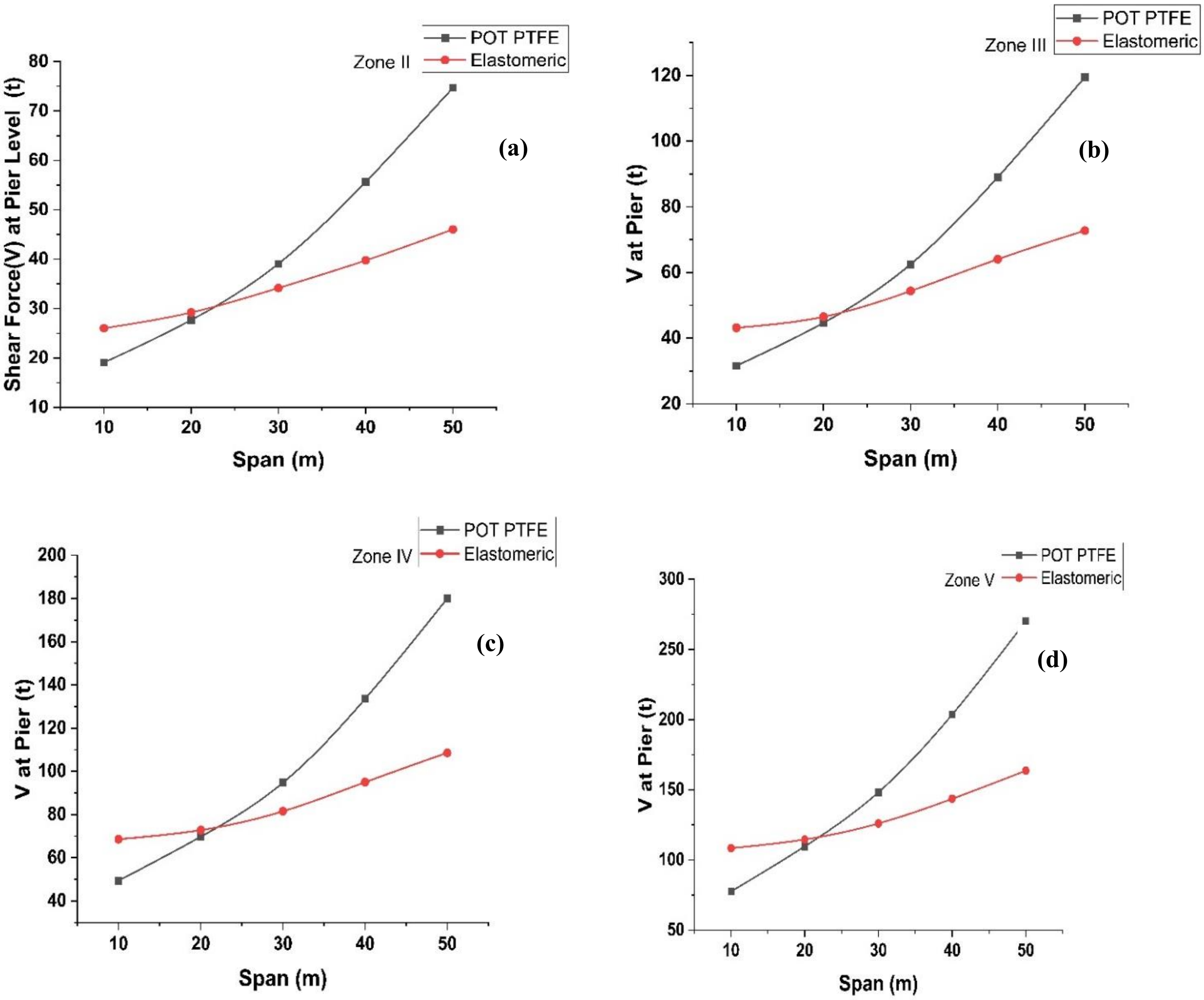

Fig. 3: Variation of Shear force for varying span

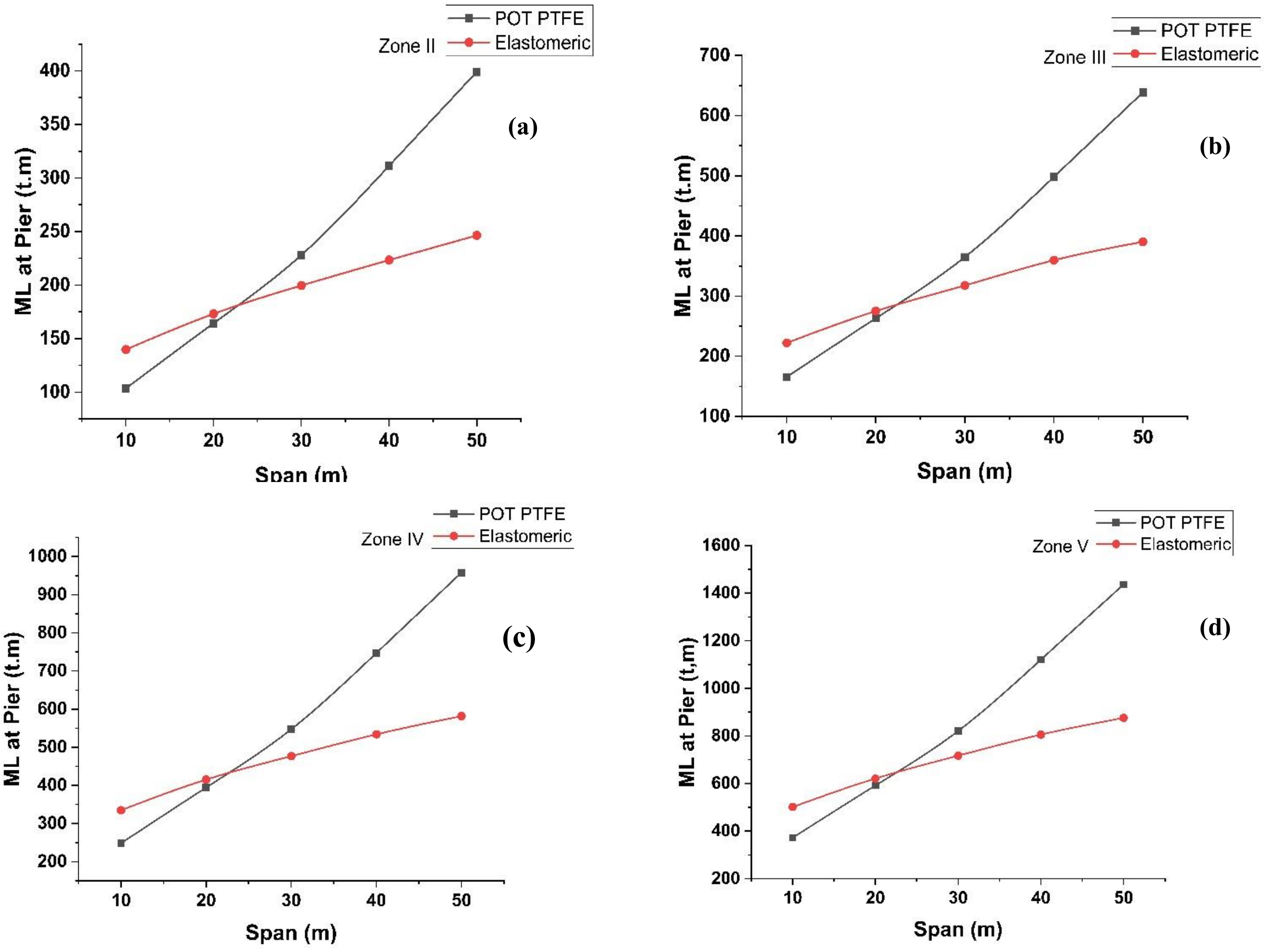

Fig. 4. Variation of Longitudinal Moment for the varying span

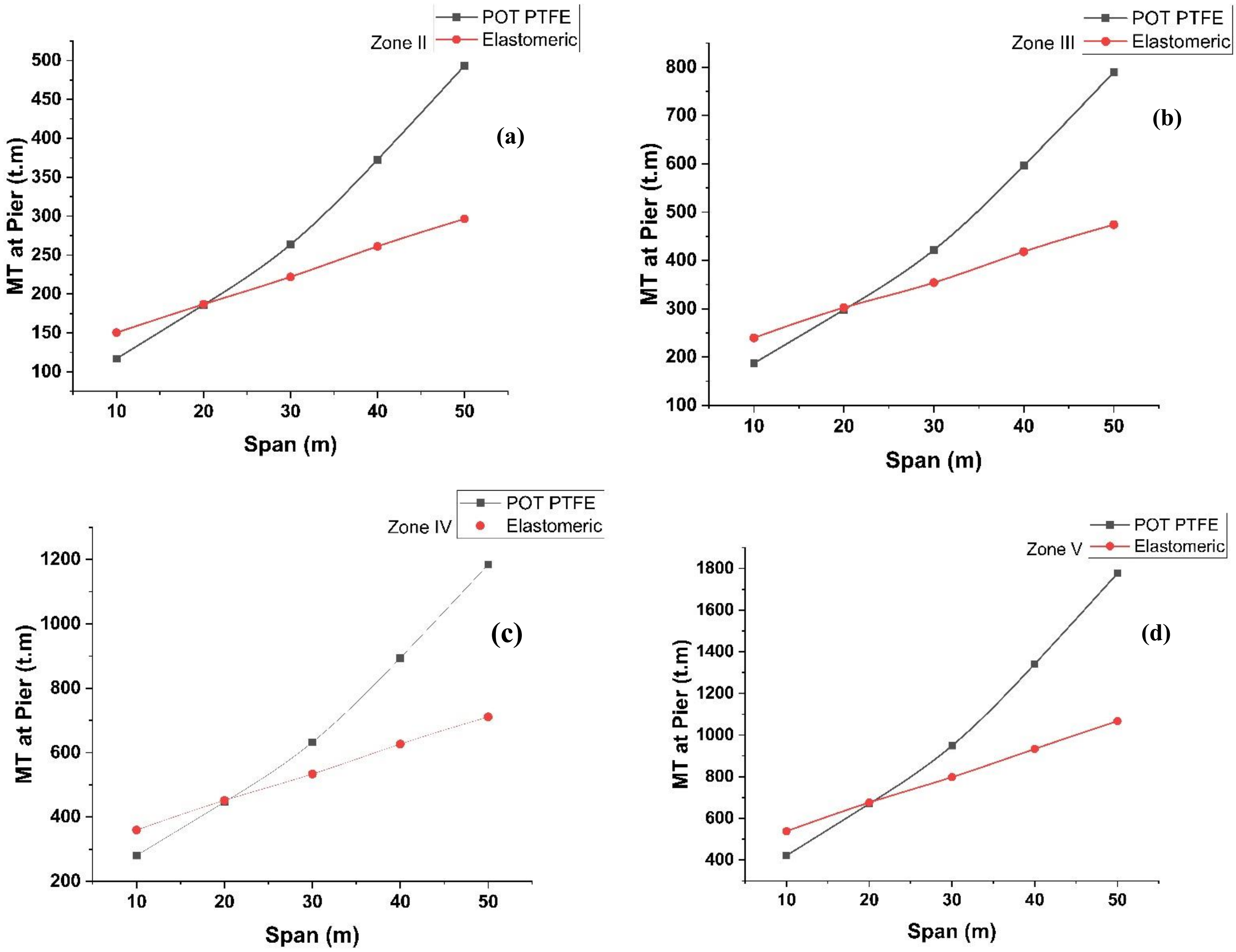

Fig.5. Variation of Transverse Moment for the varying span

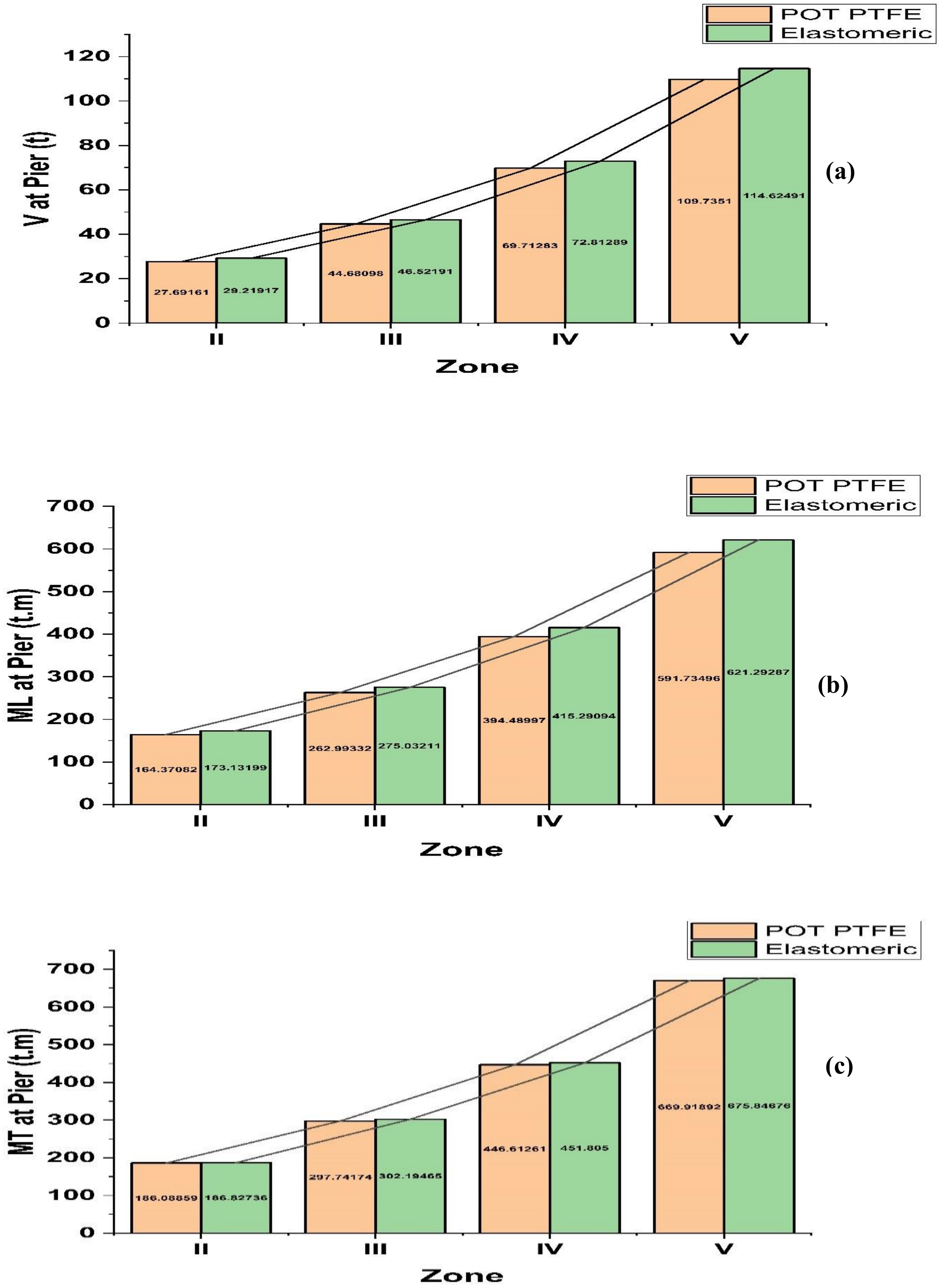

Fig. 6 Response of bridge with varying seismic zone

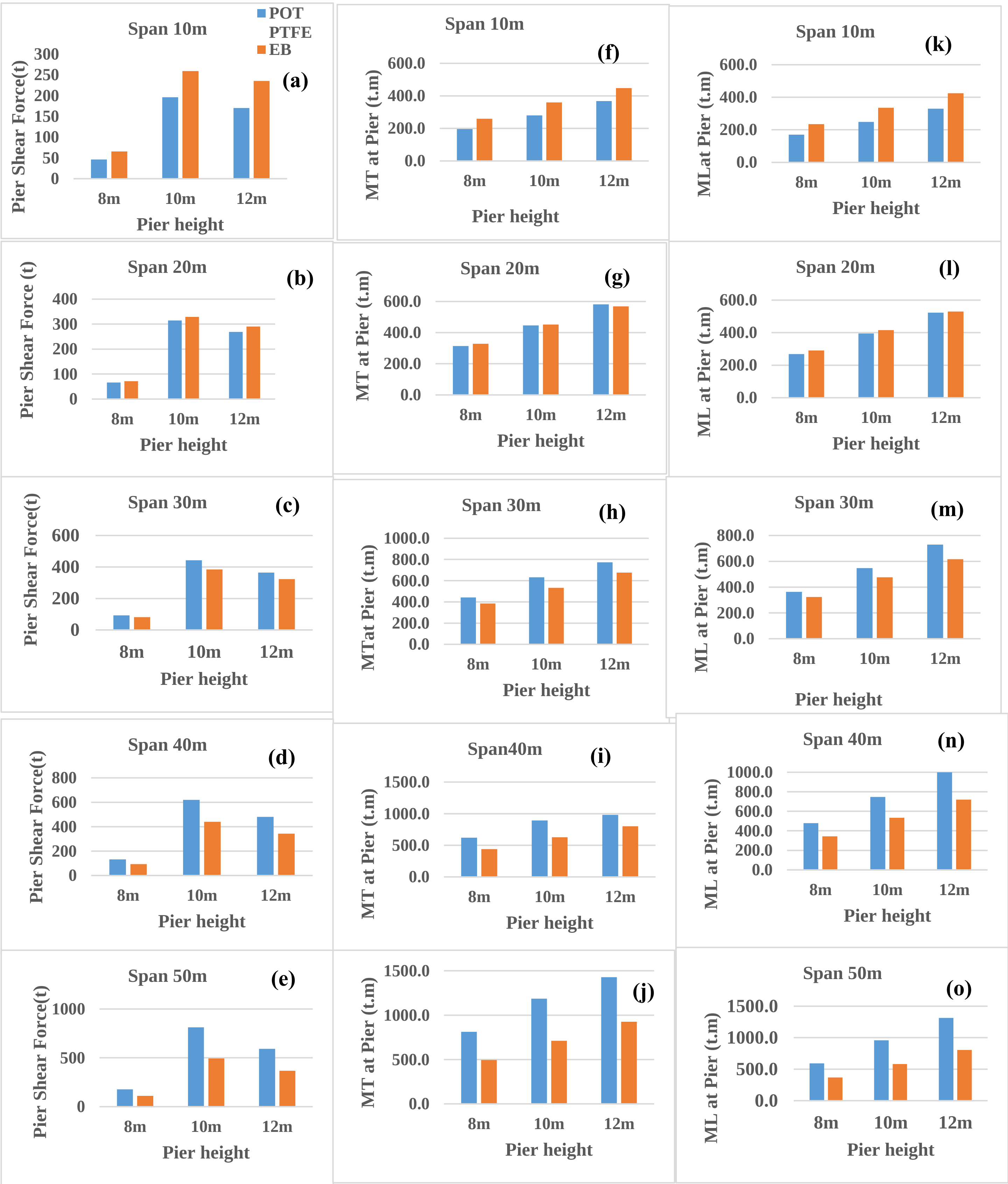

Fig. 7 Response of bridge with varying Pier height

From Fig. 3[a-d], it is clear that the elastomeric bearings (EB) effectively reduce the bridges' response under the different seismic zone of India, similar findings were observed by various resarchers[20-22].

5.2 Variation of the Seismic Zone

Several studies have been done to determine the seismic response of bridges.[28-30] The response of the girder bridges with POT PTFE and Elastomeric has been determined by varying the seismic zone from Zone II to Zone V. It has been observed that there is an increase in the shear force from 60 to 306% with PoT PTFE, however with the EBs, the shear force has been increased from 58 to 318%. The performance of the PoT PTFE is effective in the higher seismic zone. It might be due to the resistance of the friction forces in the PoT PTFE. The response of the EBs is higher due to the flexibility of the elastomer. It has also been observed that the pier longitudinal and transverse moment varies from 60 to 260% with variation from Zone II to Zone V with PoT PTFE and EBs.

From the fig. 6, It is evident that the pier response, such as Shear force, Longitudinal Moment, and Transverse moment of the girder bridges, have been found sensitive to higher seismic zones. It has also been observed that the increase in the span length increases the response of the girder bridges.

From the comparisons made in the previous section, the bearings' performance was considerably affected by the change in span length. However, these comparisons did not clarify the influence of seismic zone selection and, thereby, the effect of seismic forces on the performance of bearings in general. To understand this, the performance of 20m configuration of the bridge in different seismic zones was compared because for a 20m span, the performance of both the bearings in terms of reaction and moment developed was found to be aptly comparable and as such, the zone-wise seismic performance of the bearings was attempted to be adjudged based on this.

5.3 Variation of the Pier height:

Various researcher investigated the variation of Pier height significantly affect the response of the bridge[31-33]. In the present study, the variation of Pier has been varied as 8m, 10m and 12m. The effect of the pier height significantly affects the response of the bridge in terms of Pier shear force, pier longitudinal and transverse moment of the bridge. The effect of pier height has been observed for each case of varying span with PoT PTFE and Elastomeric Bearing.

From the Fig.7(a-e), For a variation of 8m to 10m of Pier height, it has been observed that the pier shear force has been increased. However, after 10m, pier shear force has been decreased with POT and PTFE bearings. However, the pier shear forces are found lower with PoT PTFE Bearings.

From Fig 7 (f-j), The transverse moments have been increased for a variation of the Pier height from 8m to 10m up to 46% and 44% with POT PTFE and EB bearings, respectively. However, for a variation of 10m to 12m, the pier transverse moment has been increased up to 44% and 30%, with POT PTFE and EB bearings.

From Figure 7(k-o), The longitudinal moments have been increased for a variation of the Pier height from 8m to 10m up to 62% and 58% with POT PTFE and EB bearings, respectively. However, for a variation of 10m to 12m, the pier transverse moments have been increased up to 37% and 38%, with POT PTFE and EB bearings. It can be concluded that Pier height 10m is critical for the present study. However, more investigation is required by performing different methods of analysis.

6. Conclusions

In the present study, a parametric study has been done by varying the span length of the bridge, and the seismic zone from Zone II to Zone V. Two types of bearings have been considered in the study, viz. POT PTFE and Elastomeric (EB). From the above study, the following conclusions can be drawn.

1. It has been found that the POT PTFE is effective in the higher seismic zone.
2. The performance of the elastomeric bearing is found significant to reduce the seismic zone effect.
3. It has been observed that the higher span length of the bridge tends to result in higher seismic forces in the bridges.
4. It has also been observed that the 20m span is found to be critical.
5. It has been observed that the longitudinal and transverse moment variation has the same trend of variation.
6. It has been observed that the higher seismic zone having higher seismic demand in the girder bridges and Elastomeric bearings performs better than POT PTFE.
7. The height of the pier significantly affect response of the bridge with POT PTFE and Elastomeric Bearings (EBs).
8. For the present study, Pier height 10m is found to be critical. However, more investigation is required using different methods of analysis for general recommendation.

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