SEISMIC RESPONSEOFISOLATEDCURVEDSTEELVIADUCTS UNDER LEVEL II EARTHQUAKES

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Abstract
This paper investigates the effectiveness of using seismic isolation gadgetsat the average 3-d seismic reaction of curved motorway viaducts with an emphasis on enlargement joints. Furthermore, an assessment of the effectiveness of using cable restrainers is supplied. For this purpose, the bridge seismic overall performance has been evaluated on 4 distinct radii of curvature, thinking about instances: confined and unrestrained curved viaducts. Depending at the radius of curvature,3-dimensional non-lineardynamicevaluation indicatesthe vulnerability of curved viaducts to pounding and deck unseating harm. In this look at, the performance of the use of LRB helps blended with cable restrainers on curved viaducts is validated, now no longer handiest through decreasing in all instances the feasible harm, however additionally through offering a comparable conduct in the viaducts regardless of curvature radius.
Keywords: Nonlineardynamicreaction,unseatingpreventiongadget,seismiclayout

1. INTRODUCTION

In current years, horizontally curvedmetallic viaducts have come to be an crucial thing in present day motorway structures asthe maximum possible alternative at complex interchanges or river crossings in whichgeometric regulations and constraints of restricted web page area make extraordinarilycomplex the adoption of standardinstantly superstructures.

Curved alignments offer, similarly,the blessings of aestheticallypleasing,site visitorssightdistancegrowth,asproperlyas economically aggressive constructioncharges in regards to instantly bridges. On the contrary, metallic viaducts withcurvedconfigurations might alsoadditionally preserve extreme seismic harm thanks to rotation ofthe superstructure or displacement towards the outsideofthecurvelineduetocomplicatedvibrations occurringat some point ofsturdyearthquakefloormotions1).

The South Fork Eel River Bridge, acurved metallic girder bridge placed forty nine km from the epicenter of the 1992Petrolia earthquake, sustained great harm athinge places withamassiveeffectonitsprovider ability.Thepartialcrumble at some point of the 1994Northridge earthquake of curved bridgeson the Interstate five and State Road 14interchange is some other

instance to corroborate the seismic vulnerability ofcurved bridge systems at some point of beyond earthquakes.
During history, extreme sturdy earthquakes haveagain and again validated that in anearthquake, adjoining spans frequently vibrate
out-of-phase, inflicting distinct varieties of displacement problems. Thefirst kindis a localizedharmcausedthroughthespans pounding collectively on the joints. The 2nd kind occurswhilst the enlargement joint separates, in all likelihood permitting the deck superstructureto come to be unseated from the helping substructure if the seismically prompteddisplacements are excessively massive. Additionally, bridges with curvedconfigurationsmight also additionallypreserveextremeharmowingtorotationofthe superstructureordisplacementtowardstheoutsideofthecurvelineat some point ofanearthquake1).Forthisreason,curvedbridgeshavesufferedextremeharm in beyondearthquakes.

Theimplementationofpresent dayseismicsafetytechnology hasaccredited the seismic modernization of bridges via the set up ofcable restrainers that offer connection among adjoining spans. The purpose is to save you the unseating of decks from pinnacle of the piers at enlargement jointsthrough proscribing the relative actions of adjoining bridge superstructures.Moreover, cable restrainers offerafail-safefeaturethroughhelpingafallengirderunseatedintheoccasionofaextremeearthquake1).Inaddition,some othercommonlyadoptedearthquakesafetystrategyincludes changing the susceptible metallic bearing helps with seismicisolation gadgets.

Among the splendid type of seismicisolation structures, lead- rubber bearing (LRB)has observed huge utility inbridge systems. This is because of its simplicity and the blended
isolation-power dissipation feature in a unmarried compact unit. Even aleven though theutility of the cited earthquake safety techniques, the greatcomplexity related to the evaluation of curved viaducts calls for a practicalprediction of the structural reaction, specially below the intense floormotions generated through Level II earthquakes. The impact of the curvature plays
additionally an crucial position withinside the seismicconductofcurvedmotor via ducts,throughincreasing). Thebridgevulnerabilitiesat some point ofanearthquakeBasedontheaboveconsiderations,it's farclearhowthenecessity of ancorrect layout ofnewbridgesandthe seismic assessment
of current systems have come to be deeply felt issues. It is widely recognizedthat curved bridges are complicated and particular systems, whichcanbesubjectedtodistinctvibrationactionsat some point ofan earthquake.Consequently, practicalprediction of the bridge seismic reaction have to take into account the adoption ofsubtle 3- dimensional finite-detail models. While using isolators
blended with cable restrainers had been extensively studied on instantly bridges,
there may be nonetheless a need of greater correct research for curved viaducts,
specifically concerning the impact of the curvature radius. Therefore, thepurposeofthegift
look atisto analyzetheaverage overall performance of seismically remoted motorway viaducts with distinct radiiof curvature. The impact of curvature on deck unseating harm and pounding

harm is analyzed. In addition, a evaluation among confined andunrestrained motorway bridges is supplied. The look at combines usingnon-linear dynamic evaluation with a 3-dimensional bridge versiontoaccuratelyevaluatetheseismicradii of curvature withinside the occasion of extreme earthquakes.

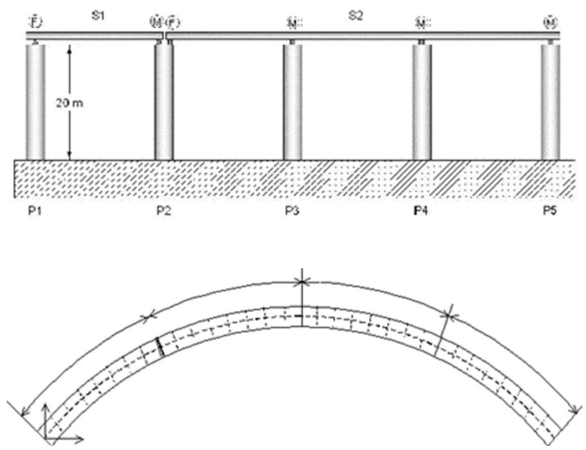
ANALYTICALMODELOFVIADUCTS

The splendid complexness associatedwith theseismic evaluation of motorway viaducts complements a practical prediction of thebridge structural responses. This reality presents a precious surroundings for the

non-linear conduct because of cloth and geometricalnon-linearities of the exceedingly massive deflection of theshape at the stresses and forces. Therefore, the seismic evaluation ofthe viaduct employs non-linear computerversion that simulates the rather non-linear reaction becauseof affects on the

enlargement joints. Non-linearities also are taken into consideration forcharacterizationof the non-linearstructural factors ofpiers,bearings andcablerestrainers.

The motorway viaduct taken into consideration withinside the evaluation iscomposedthrough a 3-span non-stopsegment related to a unmarried truely supported span. The average viaduct durationof one hundred sixty m is split in identical spans of forty m, as represented in Fig. 1-a. Thebridge alignment is horizontally curved in a round arc. Four distinct



(a) Planviewofviaduct

Fig.1Modelofcurvedhighwayviaduct

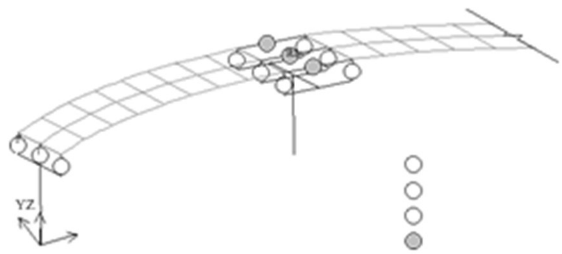


Fig.2Detailofcurvedviaductfiniteelementmodel

radii of curvature are considered measuredfrom the foundation of the round arc to the centerline of thebridge deck.Tangential configuration for each piers and bearing helpsisadopted,respecttotheglobalcoordinategadgetforthe bridge, proven withinside thefigure, inwhich theX- and Y-axes lie withinside thehorizontal aircraft whilst the Z-axis is vertical.

1.1 DeckSuperstructureandPiers

	A(m2)	*Ix*(m4)	*Iy*(m4)(1)
P1	0.45	0.3798	0.3798
P2	0.47	0.4329	0.4329
P3	0.47	0.4329	0.4329
P4	0.47	0.4329	0.4329
P5	0.45	0.3798	0.3798
G1	0.21	0.1005	0.0994
G2	0.42	0.1609	0.2182
G3	0.21	0.1005	0.0994

Table1Crosssectionalpropertiesofdeckandpiers

The bridge superstructure consists of a concrete deck slab that rests onthree I-shape steel girders, equally spacedat an interval of 2.1 m. The girders are interconnected by end-span diaphragmsaswellasintermediatediaphragmsatuniform spacing of 5.0 m. Full composite action between the slab and the girders is assumed for the superstructure model, which is treatedas a three-dimensional grillage beam system shown in

Pier Location	*K1* (MN/m)	*K2* (MN/m)	*F1* (MN)
P3,P4	49	4.9	0.49
P2,P5	36.75	3.68	0.368

Table2StructuralpropertiesofLRBsupports

Fig. 2. The deck weight is supported on five hollow boxsection steel piers of 20m height designed

according to the seismiccodeinJapan1).Twocaseshavebeenconsidered,thefirst case in which the superstructure is supported on steel bearings (SB), and the second in which the continuous section has been seismically isolated (LRB), as is shown in Figs. 1-b and 1-c. Cross sectional properties of the deck and the bridge piersaresummarizedinTable1.Densitiesofsteelandconcrete are 7850kg/m3 and2500kg/m3,respectively.

Characterization of structural pier elements is based on the fiberelementmodelizationwheretheinelasticityoftheflexure element is accounted bythe division ofthecross-section into a discrete number of longitudinal and transversal fiber regions with constitutive model based on uniaxial stress-strain relationship for each zone. The element stress resultants are determined by integration of the fiber zone stresses over the cross section of the element. At the pier locations the viaduct deck is modeled in the transverse direction as a rigid bar of lengthequaltothedeckwidth.Thistransverserigid barisusedtomodeltheinteractionsbetweendeckandpier motions3).

1.2 BearingSupports

In each instances, SB and LRB, metallicconstant bearing helps (proveninFig.three-a)areinstalled throughout thefullwidthontheleftgive up of the truely-supported span (S1), resting at the Pier 1 (P1). Steel curler
bearings on the proper give up at the Pier 2 (P2) permit for motion withinside thelongitudinal (tangent to the curved superstructure) route whilst confinedwithinside the transverseradial route.Coulomb frictionpressureis taken intoaccountin numerical evaluation forcurler bearings, which can be modeled through

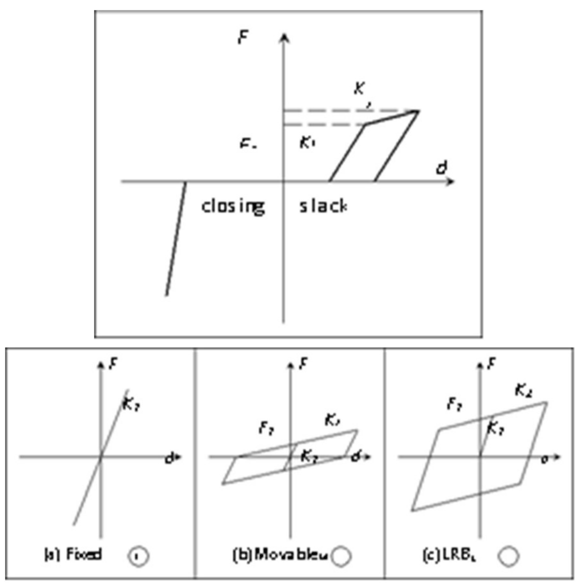


Fig.3Analyticalmodelsofbearingsupports

using the bilinear rectangle displacement-load relationship, shown in Fig. 3-b.

The continuous section (S2) inSB is supportedonfourpier units (P2, P3, P4 and P5)bysteel bearings. Steel fixed bearing at top of P2 and steel roller bearings at top of P3, P4 and P5. On theotherhand,

theisolated continuoussection(S2)in LRB is supported on four pier units (P2, P3, P4 and P5) by LRB. The left end is resting on the same P2 that supports S1, and at the right end on top of P5. Orientation of LRBs is such as to allow for longitudinal and transverse movements. LRB supports are represented by the bilinear force-displacement hysteresis loop presented in Fig. 3-c.
Theprincipalparametersthatcharacterizetheanalytical model are the pre-yield stiffness K1, corresponding to combinedstiffnessoftherubberbearingandtheleadcore,
the stiffnessoftherubberK2and the yield forceofthe lead core F1. The structural properties of LRB supports are showninTable2.Thedevicesaredesignedforoptimum yieldforceleveltosuperstructureweightratio(F1/W=0.1) and pre-yield to post-yield stiffness ratio (K1/K2 =10.0), whichprovidemaximumseismicenergydissipation capacityaswellaslimiteddisplacements4).
lateral side stoppersAccording to recommendations of Specifications for HighwayBridgesinJapan,thepre-yieldtopost-yield stiffnessratio (K1/K2)of theLRB ispreselected toensure a moderate period shift. Characteristics of isolation bearings are selected to obtain periods slightly larger than twice the fundamental period of the bridge when no isolation is applied (around 0.6 seconds in all cases). For the isolated models, the fundamental natural periods correspond to the modal shape in the longitudinaldirection of the bridge, and the values in all isolated cases are about 1.3 seconds.

1.3 ExpansionJoint

The emoted and non-remoted

sections of the viaduct are separated, introducing an opening identical to the width of theenlargement joint beginning amongadjoining spans if you want to permit for contraction and enlargement of the street deckfrom creep, shrinkage, temperature fluctuations and site visitors with out generatingconstraint forces withinside the shape. In the occasion of sturdy earthquakes, the enlargement joint hole of zero.1m might be closed ensuing in collision among deck superstructures.

The pounding phenomenon is modeledthe use of effect spring factors for which the compression-handiest bilinear hole detailisfurnishedwithaspringofstiffnessKi=980.zeroMN/m.On thealternative hand, withinside the evaluation of the confinedmodels, if you want to saveyou immoderate beginning of the enlargement joint hole,it's far furnished extra fail-safe
safety in opposition to excessive seismic masses; for this purpose, unseating cablerestrainers gadgets are anchored to the 3 girder ends (1 unit in line with girder)connecting each adjoining superstructures throughout the enlargementjoint.Cable restrainers are exceedingly easy systems.Previous studies on cable restrainer overall performance and layout has blanketed laboratorytestingofcablerestrainersfive)andassessmentandimprovement of layout procedures6-11).Post-earthquake reviews from the 1989 Loma Prieta and the 1994 NorthridgeEarthquakeshaveproventhatmanycablerestrainershad beenfoundtohaveworkedcorrectlyat

some point oftheearthquakes12),stopping truly -supported spans from falling from theirhelps. However, the crumble of bridges which includes the Gavin Canyonundercrossing and the Route 14/five separation at some point of the 1994NorthridgeEarthquakeprovedthatinadequaterestrainerlayoutcanhavecatastrophiceffects13).Lar geseismicforces areprobable to purpose both the cables tointerrupt or the bridgediaphragm partitions at the 2 ends of the cables to go through a punch-viamovement at some point of a extreme earthquakeThe seismic restrainers, illustrated in Fig. four, have
been modeled as tension-handiest spring factors furnished with a slack of zero.1/2 m,
a price outfitted to deal with the predicted deck thermal actions proscribing theactivation of the gadget speciallyforearthquakeloading.Initially,restrainers behave elastically with stiffness K1,whilst their plasticityis addedthroughthe yield pressure (F1)and the post-yieldingstiffness(K2=zero.05K1).Finally,thefailurestatementistakenintoaccountforultimatepower F2,and due to the fact then, adjoining spans can
separate freely with none movementoftheunseatingpreventiondevice.ThestructuralhousesofcablerestraineraresuppliedinTable three14
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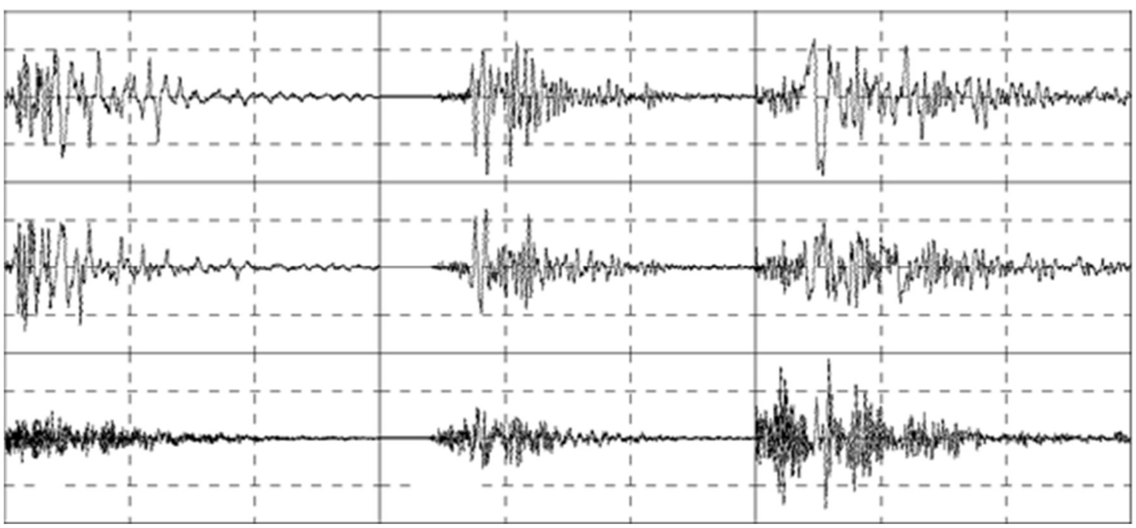


	Units	Value
E	(Gpa)	200
A	$*10\text{-}3(m^2)$	1.765
L	(m)	1.73
K1	(MN/m)	204.06
K2	(MN/m)	10.203
F1	(MN)	2.584
F2	(MN)	3.04

Table34tructuralpropertiesofcablerestrainers

2. METHODOFANALYSIS

The bridge version is developedin-residence the use of the Fortran programming language. The evaluation at the motorwaybridge version is performed the use of an analytical technique primarily based totally at thelastplastic finite displacement dynamic reaction evaluation. The governingnonlinear equation ofmovement may bederived through the precept of power that the outside paintings isabsorbed throughthe paintings of internal,inertial and damping forces for any small admissiblemovementthatsatisfiescompatibilityandessentialboundarysituations.Hence,theincrementalfinitedetaildynamic equilibrium equation at time t+ t over all of thefactors, may be expressed withinside the following matrix form
structural accelerations, velocities, incrementaldisplacements and earthquake accelerations at time t+ t, respectively. The incremental equation of movement money owed for
each geometrical and cloth nonlinearities. Material nonlinearityis added via the bilinear
elastic-plastic strain-stress courting of the beam-column detail,
incorporating a uniaxial yield criterion and kinematic stress-hardening rule.
The yield strainis 235.four MPa, the
elastic modulus is 2 hundred GPa and the stress hardening in plastic place is zero.01.
Newmark's step-through-step technique of
steady acceleration is formulated for the mixing of equation of movement.
Newmark's integration parameters (β=1/four,
γ=1/2) are decided on to provide the
required integration balance and most efficient end result accuracy. The equation of
movement is solved for the incremental displacement the use of the Newton-Raphson
new release scheme in which the stiffness matrix is up to date at every increment to
take into accountgeometricalandclothnonlinearitisandtospeedtoconvergence rate. The dampingmechanismis addedwithinside the evaluation via the Rayleigh damping matrix, expressed as a linear mixture of the mass matrix and the stiffness matrix.

The unique values of damping coefficients are set tomake certain a relative damping price of 2% withinside the first herbal modes of the
shape.
To examine the seismic overall performance of the viaduct, the
nonlinear bridge version is subjected to the longitudinal (L), transverse (T),
and vertical (V) additivesof3 sturdy floor movement facts (Fig.
five) from the Takatori (TAK) and Kobe (KOB) Stations at some point of the 1995 Kobe
Earthquake, in addition to Rinaldi (RIN) Station, from the Northridge Earthquake in
1994.
Thelongitudinalearthquakethingshavethemotorway viaduct parallel to the X-axis of
the worldwide coordinate gadget, whilst the transverse and vertical additives areperforming withinside the Y-and Z-axes, respectively. The massive significance facts from the

1995 Kobe Earthquake and Northridge Earthquake
used on this look at, classifiedas close to-fault motions, are characterizedthroughthe presence of excessive height accelerations and sturdy pace pulses with a longlengththingasproperlyas massivefloor
displacements16).

3. NUMERICAL RESULTS

The average 3-dimensional seismicresponses of the viaducts are investigated in element via non-linear dynamicreactionevaluation. Particularemphasishasbeen centered at theenlargement joint conduct because of the intense complexity related toconnection among remoted and non -remoted sections in curved viaducts. Thebridge seismic overall performance has been evaluated on 4 distinct radii ofcurvature, 100m, 200m, 400m, and 800m, thinking about instances: viaducts with andwith out unseating cable restrainers.

4.

In the evaluation of the confined

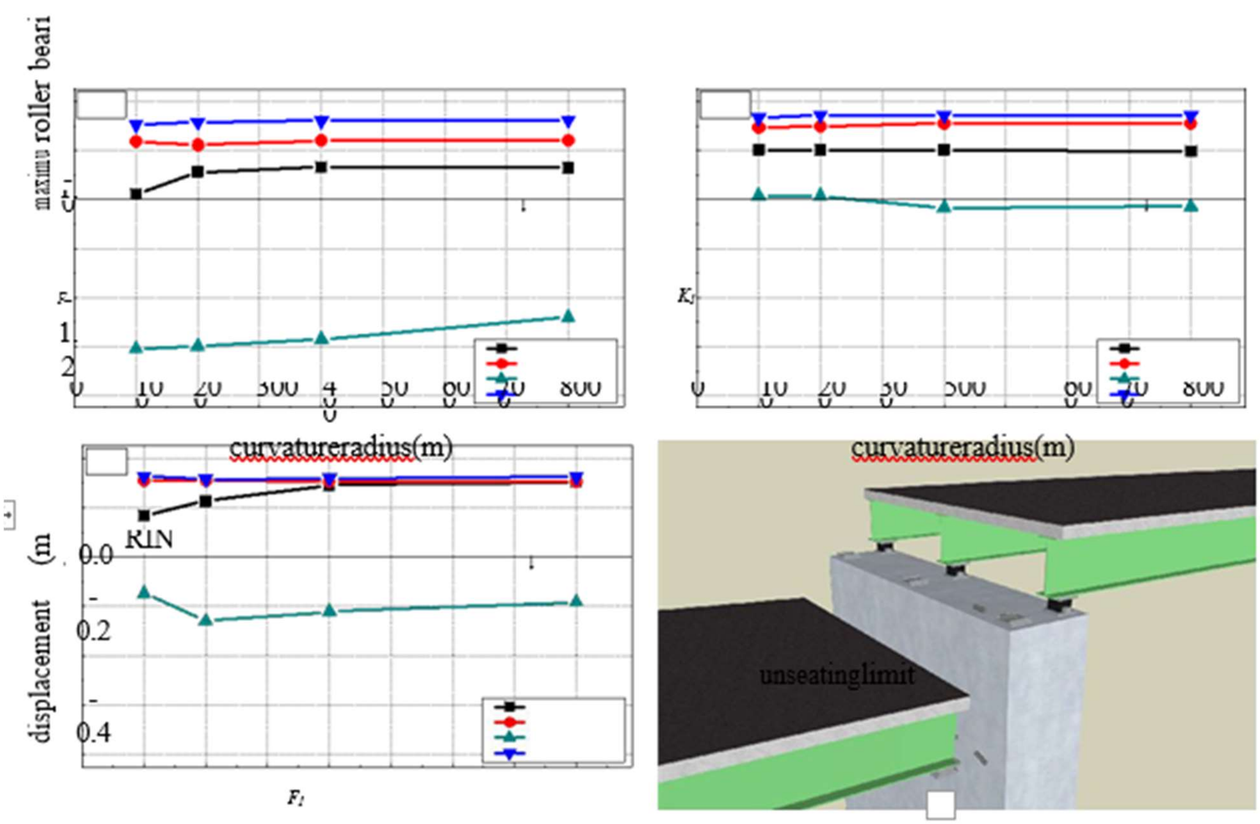
models, if you want to save you immoderate beginning of the enlargement joint hole,
unseating cable restrainers gadgets are anchored to the 3 girder ends (one
unit in line with girder) connecting each adjoining superstructures throughout the enlargement
joint. The seismic restrainers, illustrated in Fig. four, had been modeled as
tension-handiest spring factors furnished with a slack of zero.025m, a price outfitted to
accommodate the predicted deck thermal actions proscribing the activation ofthe gadget especially for earthquake loading.

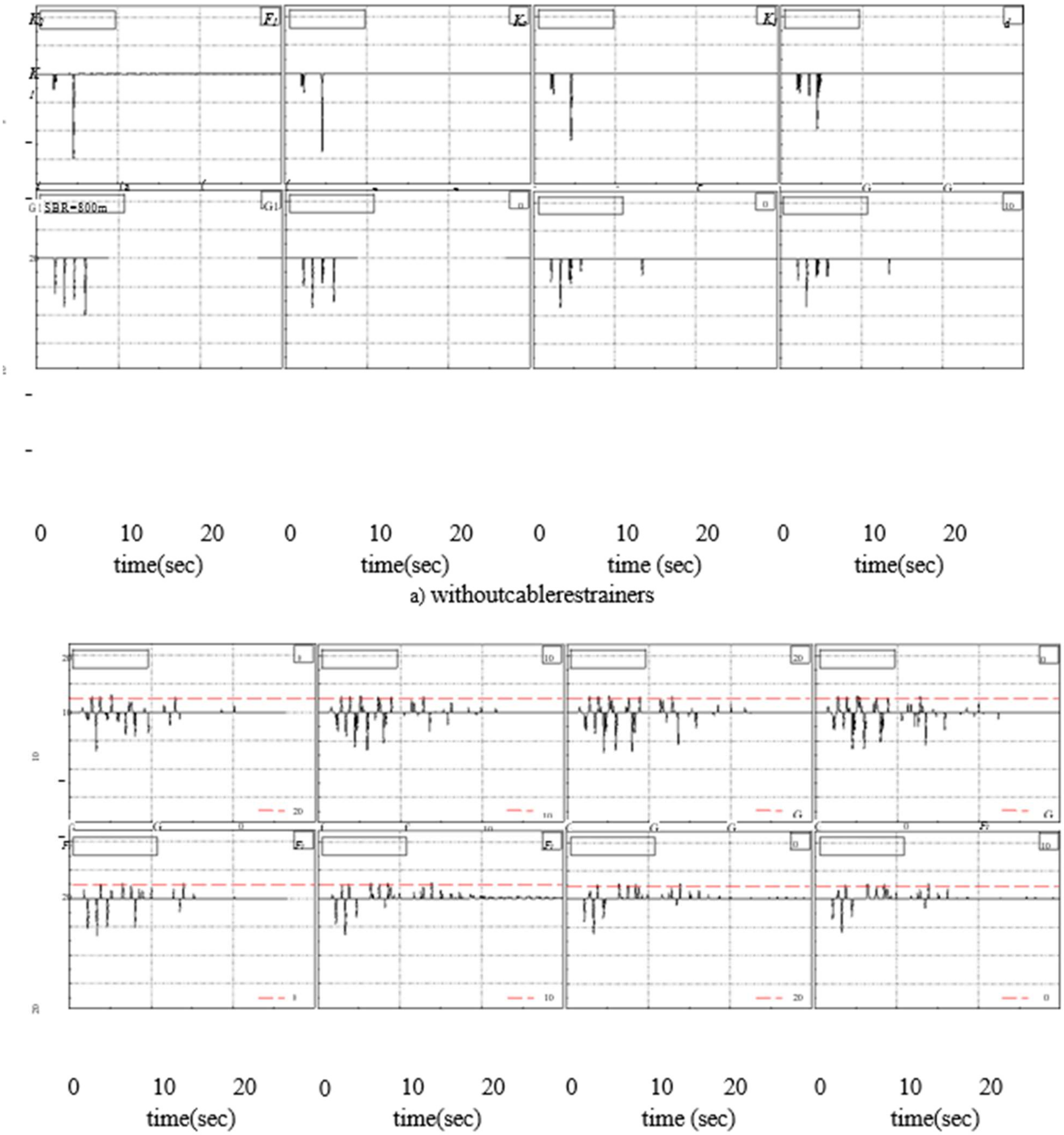
4.1 Bearing Supports

Firstly, the impact of curvatureradius on deck unseating harm is analyzed. During an earthquake, adjoining
spans can vibrate out-of-phase, ensuing in relative displacements atenlargement joints. In truely-supported spans, the prompted relative displacementsto metallic curler bearings can exceed the seat width on the pier pinnacle, inflicting thedislodgment of therollers from thebearing meeting and the following crumble because of deck superstructureunseating. The most curler bearing displacement withinside the bad tangentialroute has been mounted because the harm index to assess the potentialopportunityofdeckunseating.Forthislook at,arestrictofzero.forty m has been constant to decide the excessive unseatingchance for current bridgeswith slim metallic pier caps that offer shortseat widths.

First, the unrestrained viaducts areanalyzed in phrases of the mostdisplacementatthemetalliccurlerbearing.Theeffects, proven in Fig. 6,suggest that maximum of the viaducts supportedon metallic bearings andsubjected to the 3 earthquake inputs clearlyoverpass the unseating restrict, being handiest 100m and 200m viaducts in KOB theexceptions. It may be found that TAK represents the worst circumstance for all
the curvatures. In the equal way, the reaction received from RIN indicates extraordinarilyexcessive displacements. KOB affords smaller values; but the ones are nonetheless nearor maybe over the unseating restrict forthebridgeswith400mand800mcurvatureradius.Itcanbe observed the immoderate

vulnerability to unseating harm ofcurved viaducts prepared with metallic bearings. The reaction of theviaductprepared withLRBhelpsisadditionallyproveninFig.6. It canbefound thatas soon as the non-stopsegmenthas been remoted, its seismic reaction
improves extensively in all of the curvatures. However, despite the fact that the valuesare awesome smaller than the ones from the metallic instances, there may be nonetheless a clearimpact of the curvature radius in phrases of most curler bearing displacementson TAK and RIN inputs.For confined viaducts, comparablevalues of most displacements at the curler bearing are found in each,metallic and LRB viaducts. Both instances gift a awesome discountat the most displacements in evaluation with the
received withinside the unrestrained instances; specifically withinside the bridges with 100mcurvature radius. From the effects, it could be found that the enter reportrepresenting the worst state of affairs isTAK enter, generating extensively betterdisplacementsthat installed threat thesuperstructure of the viaducts.





a) withoutcablerestrainers

b) withcablerestrainers

Fig.8 MaximumImpactforcesatexpansionjointfromTAK

The last two viaducts with 400m and 800m of curvature radii have impact forces slightly less severe in most of the cases. It can be noticed the extremely high impact forces presented in the more curved viaducts with steel bearings as well as in the cases with LRB supports.Intheworstcondition, viaductwith100mandsteel bearings, the maximum values reach 15 MN, while the 100m viaduct equipped with LRB supports reach just 10 MN. Fig. 8 shows the results from TAK, which represents the most severe condition. For the viaducts equipped with cable restrainers, the reduction in the

possibility of pounding damage is significant. Firstly, the use of restrainers reduces the impact forces in all viaducts, despite the curvature radius and the differences on bearingsupports;thiscanbenoticedeveninthebridgewithradius of curvature of 100m. This effect applies as well to the other bridges with 200m, 400m and 800m of curvature radii, as presented in Fig. 8. In the results fromthe restrained viaducts, it is still possible to observe the advantages of replacing the steel bearings for LRBs. The use of seismic isolation devices reduces the possibility of excessive impacts at the expansion joint. Such results prove the effectiveness of the
combination of seismic isolation devices and unseating prevention system. Furthermore, it is possible to observe the remarkable advantages of the use of a deck unseating prevention system based on cable restrainers, especially in terms of pounding damage at the expansion joint. The results indicate that the installation of cable restrainers effectively reduces the relative displacements at the expansion joint, and therefore the possibility of pounding damage.

4.2 PieratExpansionJoint

First, for unrestrained viaducts, the seismic reactionin phrases of displacements on the pinnacleof the piers with metallic bearings is analyzed. For TAK enter, that's the worstcircumstance for the viaducts,the effects display immoderate displacements on the pinnacleofP2. Fig. 9 indicates the pier pinnacledisplacementtrajectories foundatpinnacleofthepierhelpingtheenlargementjoint.Itcanbefound the excessive valuesreached through theviaducts without a seismic isolation and no cable restrainers.For the viaductsin which LRBs had been installed, the seismic reaction affords a awesome improvement at the displacements of pinnacle of the pie

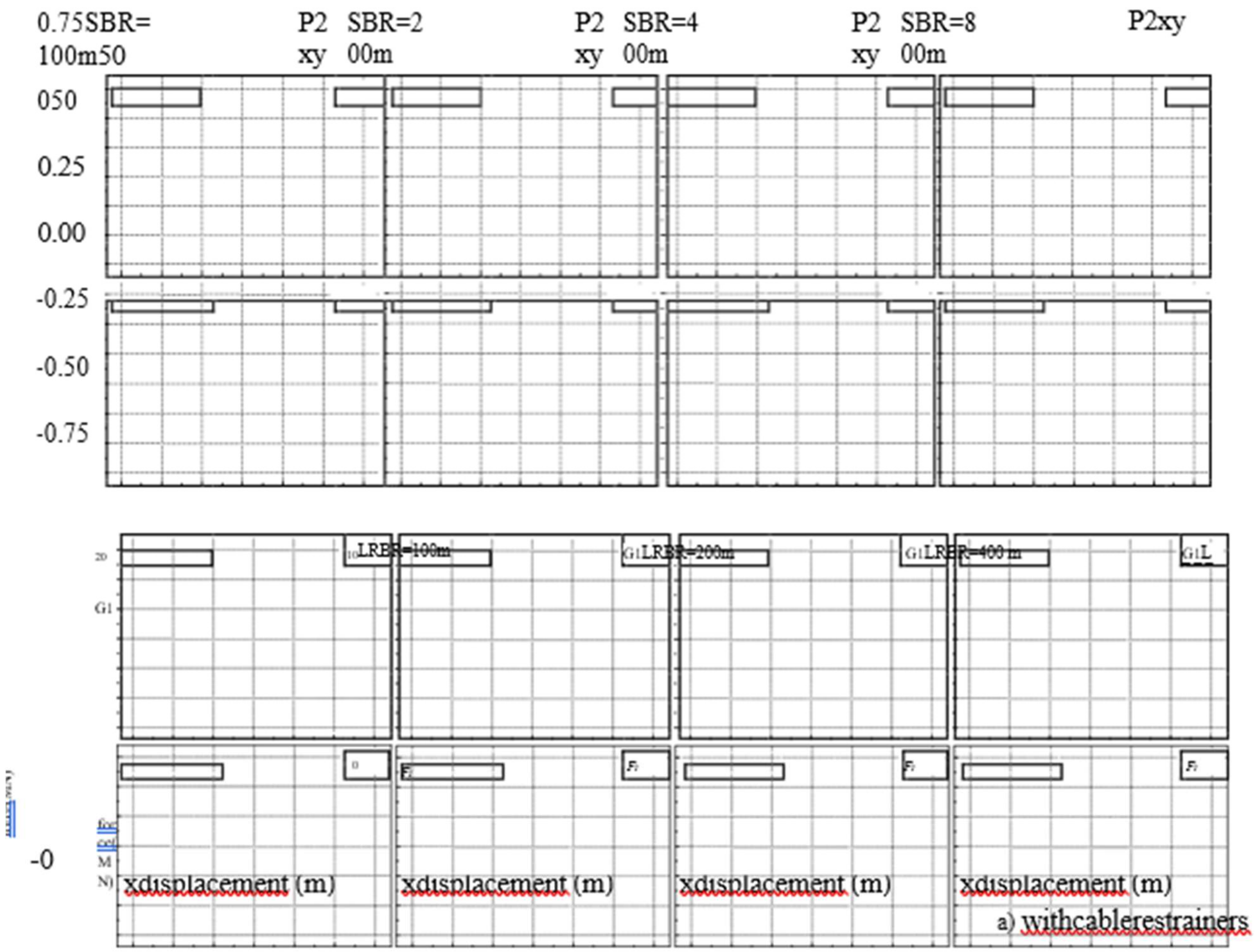


Fig.9 PiertopdisplacementtrajectoriesatP2fromTAKinput

Fig.9PiertopdisplacementtrajectoriesatP2fromTAKinput

CONCLUSIONS

The effectiveness of seismic isolation if you want to lessen the opportunity of seismic harm on curved motorway viaducts has been analyzed. The 3-dimensional nonlinear seismic dynamic reaction has been evaluated .Moreover, the effectiveness of cable restrainers to mitigate earthquake harm via connection among remoted and non-remoted sections of curved metallic viaducts is evaluated. The research effects offer enough proof for the following conclusions:

The calculated effects clearly exhibit that curved viaducts are greater susceptible to deck unseating harm. It has been found that for greater curved viaducts, this opportunity growth extensively. However, this kind of seismic harm is decreased to begin with through the set up of LRBs and finally through the set up of cable restrainers. Moreover, using cable restrainers presents to the bridge a comparable conduct in case of curved and instantly tending bridges, regardless of the curvature radii. In phrases of tangential joint residual harm, curved viaducts are observed specifically susceptible. This harm became extensively decreased as soon as

LRBs had been installed. In confined viaducts, an crucial discount of the residual joint tangential displacement is preferred and comparable values of residual joint tangential displacement are received .Also curved viaducts are observed susceptible to pounding harm. Viaducts supported on metallic bearings constitute theworst situations In phrases of seismic reaction, whilst seismically remoted instances show to be greater effective. A considerable discount with inside the effect forces on the enlargement joint is found through the set up of LRB helps. Furthermore , despite the fact that the variations at the radii of curvature some of the viaducts, the utility of cable restrainers reduces the opportunity of pounding harm. Finally, on this evaluation, the effectiveness of seismic isolation blended with using cable restrainers on curved motorway viaducts is validated, now no longer handiest through decreasing in allinstances thefeasibleharmhowever additionallythroughofferinga comparableconduct withinside the viaducts regardless of curvature radius.

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