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# Seismic analysis of isolated bridges

C.Nuti
*Departamento di Scienze Storia dell'Arch. e Restauro, University G.D'Annunzio, Pescara, Italy*

ABSTRACT: The nonlinear dynamic response of an r.c. bridge having mechanical dissipation devices (i/d) between deck and piers is presented. Different design strategies are investigated, having different relative resistances between piers and i/d's. The influence of strain hardening of i/d's, the shape of their force displacement curve and, last but not the least, non synchronism of seismic input is considered. Results show that i/d hardening is important for the evaluation both of pier damage and i/d displacement, non synchronism for the evaluation of i/d displacement.

## 1 INTRODUCTION AND SCOPE

Seismic design of bridges having dissipation-isolation devices between piers and deck is not yet codified and can still be considered a matter of engineering art. At present a number of application have been realized even though no one of those bridges has sustained a strong earthquake as yet.

Codes for the design of structures with isolators and dissipators are now appearing.

For isolators the general criteria to be adopted are now going to become well understood even if some caution needs to be maintained with respect to the new technology and work is needed essentially in the calibration of the parameters involved which should be based on probabilistic concepts. In the case of dissipators problems still holds concerning the design strategy and the inference of the various parameters on seismic response and a lot is still to be done in order to simplify the design and verification. The problem is well different from the usual base isolation: in the latter case in fact forces are reduced thank to period elongation, a technic which is not much effective for bridges which have in general long periods, while in case of dissipators the concept is the cut off of the force transmitted from the deck to the piers. The nonlinear response is obviously implied, a field in which the number of governing parameters is larger than for linear cases.

In the case of bridges dissipation devices (i/d) are placed between piers and deck, therefore, if, as in many cases, piers yield, the forecasting of the total response can be complicated.

In the present study a continuous deck bridge having four span of 50 m. each, fig.1, having isolation devices (i/d) between deck and the two lateral piers, a hinge on the central pier, and rollers in both horizontal direction at the abutments, is analyzed, obtaining the response statistics by a nonlinear dynamic analysis for increasing seismic intensity from 0,3 g to 0,6 g peak ground acceleration. Three different choices for the relative ratio between yield strength of the isolation device and yielding shear of the piers are considered with an increase of the strength of the pier or a decrease of the yield strength of the i/d with respect to the basic choice described in the next paragraph.

The influence of i/d strain hardening "H" is considered, this parameter being of difficult accurate determination for real cases, while resulting important for the assessment of the global response: three values are considered H=0.0,0.01,0.05.

A second parameter is the shape of the i/d force-displacement curve, depending on the curvature of the transition from elastic to plastic branch, the equation being the well known Menegotto-Pinto model: three values of the exponent R in the equation are considered R=20,5,2, which means from an abrupt change from elastic to plastic branch, to a very smooth one.

In a previous study [Nuti 1991] the influence of the duration of the accelerograms had been investigated. When the maximum ductility demand is the governing parameter for the assessment of collapse, and the input is composed of artificial accelerograms matching the same elastic response spectrum, the statistics based on samples having a duration of 27 or 20 secs are practically coincident. The number of accelerograms needed to obtain a stable evaluation of the response mean and standard devi-

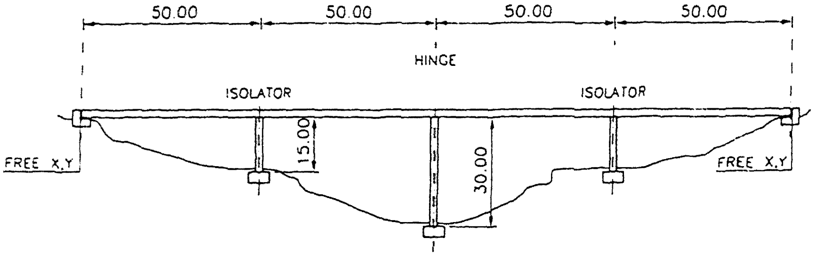

Figure 1. Elevation of the bridge

ation was 10 (the generation program was the well known Simqke).

As a final parameter the nonsynchronism of the seismic input is considered in its simplest modellization of a time shift equal to d/v, being d the distance between the piers, and v the transmission wave velocity. Two values of v have been considered v=300 m/sec, v=600 m/sec, compatible with the characteristics of the response spectrum considered in the generation and design: EC8 for medium soils.

## 2 DESIGN CRITERIA

The new draft of EC8.2, for seismic design of R.C conventional bridges, requires to evaluate design member forces trhought a linear dynamic analysis, dividing the resulting forces by a behavior factor: 3.5. Reference peak ground acceleration, in this case 0.40 g, must be multiplied by an importance factor 1.2. An over strength factor of 1.6 is to be assumed for the evaluation of the design shear. The nonlinear response of the same bridge with a conventional design has been carried out in [Nuti 1991a].

The following design criteria have been adopted for the bridge having dissipating devices [Kolias et al.1991].

On the base of an elastic analysis scaled to 0.1 g, yielding forces of the i/d devices are obtained. The base monument and shear of the piers are obtained multiplying the results of the elastic analysis by a factor 1.1, thus taking into account for the possible over strength of the i/d devices. This forces must be resisted without exceeding for concrete $\varepsilon_c=0.0035$ and for shell $\varepsilon_s=0.01$. No over capacity for shear is considered. The resulting longitudinal reinforcement of the piers is 2.74%, while transverse reinforcement is 18 mm diameter spiral having 150 mm pitch.

Reinforcement saving, with respect to conventional design, are 20% for longitudinal and 67% for transverse [Nuti 1991a].

The previous described is the basic design case named case B in the following. Two additional cases have been considered. The first, case A, consists in a 20% increase of the pier yielding force, the second, case C, consists in a 20% decrease of the i/d yielding force, without modifying the other parameters of the basic case.

## 3 NONLINEAR DYNAMIC ANALYSIS.

The nonlinear step by step dynamic analysis has been carried out and the statistics of the response in terms of total damage of the lateral pier and i/d displacement have been obtained for the three design considered for the various combinations of the parameters. The base section is governed by a Takeda model, 2nd order effects are considered.

The i/d's are modeled by Menegotto-Pinto laws. The analyses have been carried out for the base section at the mean resistances and for case A and B at design resistances too. Table 1 shows yielding forces for the i/d's and for the piers.

Tab.1-i/d (F) and pier (F) yielding shears

| CASE | Design.Res. | | Mean Res. | |
|---|---|---|---|---|
| | F | R | F | R |
| A | 271 | 288 | 271 | 301 |
| B | 325 | 288 | 325 | 301 |
| C | | | 325 | 361 |

It is to be noted that the design criteria imply, in the basic case, a yielding of the piers before the i/d's can work, the design forces are in fact obtained at a ductility level of about 2.

## 4 RESULTS

In order to shorten the presentation the longitudinal analysis only is presented. In this manner the effects of the deck flexibility do not complicate the interpretation of the res-

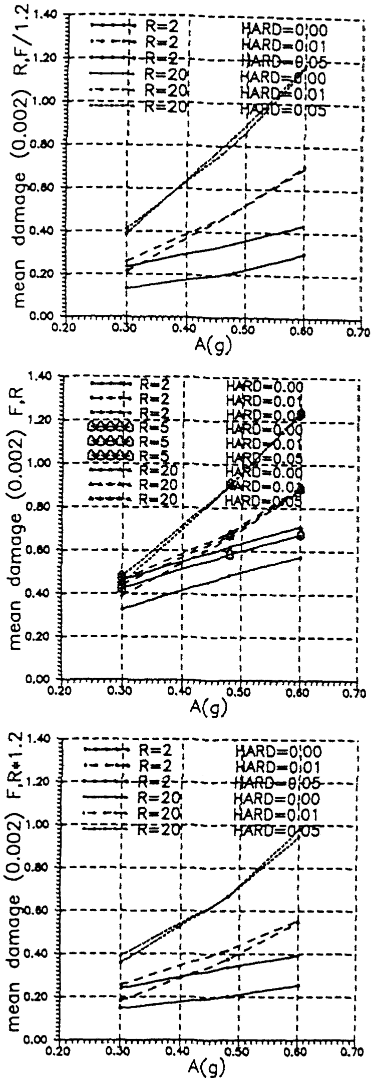

Figure 2. Mean damages versus P.G.A. for mean base resistance,α=0.02. Top case A, middle case B, bottom case C.

nic curvature, $x$=maximum response curvature $E_d$=dissipated energy, $E_n$=energy at monotonic collapse, α=damage parameter for energy here considered as 0.02 or 0.10.

In fig. 2 mean damages are shown for the three designs in the case of mean resistances, with α=0,002, as a function of PGA.

The strong influence of hardening can be observed. As hardening increases the dissipators *loose their capability of* cutting the shear transmitted to the piers, therefore pier damage increases. It can be observed that very similar results are obtained between the basic case B and case A (reduced yielding resistance of the isolator) if hardening>0.

An unexpected result is the relevant influence of the shape of the curve in the case of (ubrupt stiffness change) the damage doubles. The influence of R is insignificant for hardening 0.01 and 0.05.

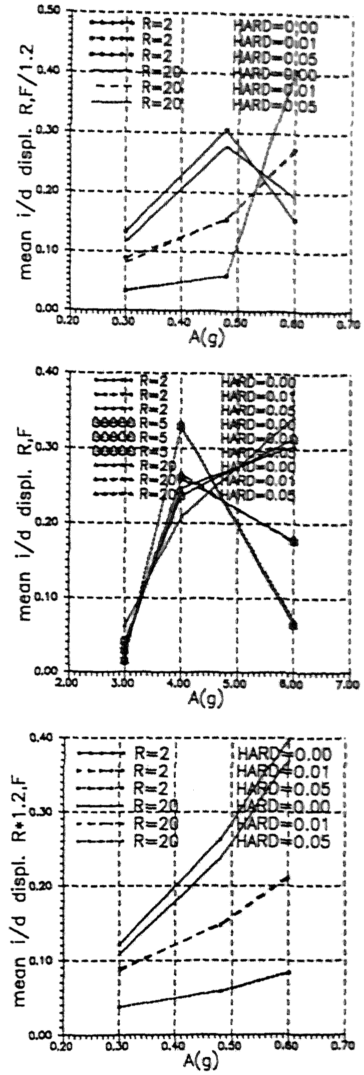

Figure 3. Mean i/d displ. versus P.G.A. mean base resistance,α=0.02: Top case A, middle case B,bottom case C.

In fig. 3 the displacements of i/d for the same cases of fig.2 are shown. Hardening has a great influence on i/d response which differs much for the three designs. Case C is the only 'regular' with the greatest displacements for the elastic plastic case. Case B shows small differences up to the reference intensity 0.48g, while displacements can lower for higher intensity and seem inversely proportional to hardening. Case A at 0.6g has an inverse behavior with respect to case B. Case B using design resistances has given regular results similar to case C.

Finally the shape of the i/d curve has a

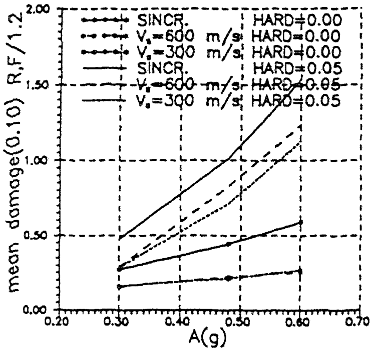

Figure 4. Damages ,case A, α=0.10, non synchronous (dotted) and synchronous cases

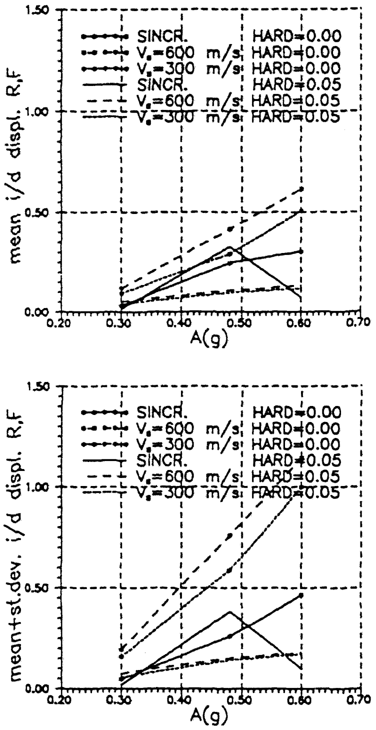

Figure 5. I/d displacements, left mean, right mean+σ,case B.

small influence on total displacement in the elastic plastic case too.

The effect of the simple non synchronism model considered (time shift) is shown in fig. 4, for what concerns mean damage (α=0.10, case A). Non synchronism leads to a substantial reduction of damage, as expected. Synchronous case, hard=0, leads to equivalent damage levels with respect to the non synchronous cases with hard.=0.05. The variance has resulted small for synchronous and non synchronous input.

Non synchronous I/d displacements (fig.5) are larger in the elastic plastic case are larger, and very disperse around mean value; while when the i/d has some hardening the displacements reduce and the variance is small. It can be observed also that the unexpected phenomenon of displacement reduction for increasing seismic intensity present in fig.3 disappears for non synchronous input. Results concerning displacements for non synchronous input have been systematically obtained for the tree design cases considered.

## 5 *CONCLUSIONS*

The study doesn't permit to draw final conclusions concerning the design strategy. However the relative importance of some parameters whose inherent variability must be considered in the analysis arises.

The possible range of values of i/d hardening cannot be simplified by the definition of a simple deterministic value, the sensitivity analysis being essential.

An accurate modeling of the force displacement curve at least for elastic plastic i/d is essential.

I/d displacements can lower for increaseing seismic intensity.

The problem of non synchronism can be disregarded for the evaluation of pier damage but needs an accurate consideration for what concerns i/d displacements.

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