Utilization of an Expert System for the Preliminary Design of Seismically Isolated Bridges

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SUMMARY:
Seismic design of isolated bridges involves preliminary and detailed design. However conceptual and preliminary design can be proved a non-straightforward procedure. Given the lack of detailed design guidelines to ensure, at this preliminary stage, compliance with the above requirements, a "trial and error" procedure is typically followed in the design office to decide on the most appropriate design scheme. A decision-making process based on the current Eurocode's provisions is developed and is complemented by additional criteria set according to expert judgment, laboratory testing and research findings. Emphasis was given to the major parameters of the problem that influence the design of the seismic isolation system.

Keywords: bridges, seismic isolation, preliminary design, expert system, software

1. INTRODUCTION

Rubber bearings including elastomeric bearings and seismic isolators are installed to improve the seismic performance of bridges (Kunde et al., 2003). In Japan as well as in other countries around the world, such bearings were installed as part of retrofitting schemes aimed to upgrade the seismic safety of various types of bridges (Hoshikuma et al. 2012). During past earthquakes, there was no report of significant damage of rubber bearings and their high deformation performance protected the function of bridges (Kawashima, 2012). During the recent devastating Tohoku 2011 earthquake elastomeric bearings generally performed quite well under the extreme ground motions in the majority of cases, although elastomeric bearings ruptured in some bridges (Buckle et al.; 2012). A number of bridges were also damaged by the subsequent tsunami; for this type of action elastomeric bearings and the way they are installed do not protect the bridge deck from floating away. The current research aims to provide a tool that can be utilized in the preliminary design of seismically isolated bridges through an expert system specially developed for this purpose. The field of application of this expert system, which is based on the relevant provisions of Eurocode 8, relevant to actions generated from earthquake ground motions (not tsunami) as will be explained in section 2, is either newly designed bridges or the upgrading of existing bridges. It must be pointed out that the quality control of such isolation devices is of the utmost importance. Specifications for testing of the materials for the production of these isolation devices as well as of the devices themselves are described in detail (International Standard ISO 22762-1, Manos et al. (2011). Furthermore, this expert system is intended as a tool for facilitating the designer in trying various isolation schemes and not in replacing his engineering judgment.

2. PRINCIPLES OF SEISMIC ISOLATION OF BRIDGE SYSTEMS AND CURRENT CODE PROVISIONS

The seismic isolation design of bridges in Europe is performed according to the Eurocode 8 - Part 2 (CEN, 2004) and more specifically according to clause 7, which refers to the basic requirements and compliance criteria, analysis procedures and the verification of the isolating system. Annexes J and K of the Eurocode 8-Part 2 also refer to the laboratory tests required to determine the variation of the design properties of the seismic isolator units and to verify the elastomeric bearings under seismic design situations. Similar provisions exist in the US (AASHTO, 2001). The designer is also given the choice between bearings available on the international market and any other experimentally tested rubber bearing suitable for seismic isolation. The design is based on the following steps.

a) Calculation of the weight of the bridge per unit length taking into account: (a1) the dead load that depends on the deck cross section and the transverse width (the selection of the deck type is based on the span length and the construction method), (a2) additional permanent and variable loading according to Eurocode 1 (Eurocode 1 - Part 3, 2000), **b)** Selection of the shear modulus of the elastomeric (the same for all isolators) and the number of bearings per support, which can be either the same or different at each pier or abutment-support. **c)** Calculation (by the expert system) of the total effective stiffness K_{tot} of the combined foundation-pier-isolation (Naeim et al., 1999) system in the longitudinal direction of the bridge, **d)** Calculation of the effective period of the equivalent S.D.O.F that bridge, **e)** Calculation of the seismic displacement $dE_{d,x}$ of the deck in the longitudinal and transverse direction, respectively. This is done by using the elastic spectrum of Eurocode 8 (specific guidelines for seismically isolated bridges) and the S.D.O.F. approximation. **f)** Checking all isolator units included on a data base, according to Eurocode-based performance criteria and selecting the isolators satisfying these criteria.

The simplified approach described above, combined with an expert system that can undertake the task of the repetitive calculations, can facilitate the techno-economical selection of a bridge isolation system in a way that is made to satisfy all the design constraints arising from serviceability and safety-oriented code provisions, but also to maximize performance at the lowest possible cost.

3. THE PROPOSED KNOWLEDGE-BASED DECISION-MAKING SYSTEM

The methodology presented in this paper for the preliminary design of base isolated bridges is described in detail in Manos et al. (2011). The methodology applies to all bridges isolated with low damping steel laminated elastomeric bearings (LDRBs), except for those cases where monolithic pier-deck or abutment-deck connections are combined with bearing-type pier-deck connections. The verification of the methodology is given in section 3 of the paper and shows satisfactory results in straight bridges. The structure of the KBES can be summarized in the following three steps, which also conceptually comply with those proposed by Pham (1988).

3.1. Step 1: User Input

A database of bearings available on the international market and experimentally tested elastomeric bearings is first compiled consisting of the properties of the bearings, that is, shear stiffness G, shape (that is, rectangular or circular), rubber and steel plate thickness, height, and width, overall area (A) and dimensions (B_x, B_y or D). Possible bridge structural systems, characterized by a different number and length of spans (see figure 1, L, L_1), that define the total bridge length (L_{tot}), different pier heights and the mass per unit length (m), as well as initial configurations of n bearings are defined by the designer. Seismic hazard is also considered, the design seismic acceleration (Sa), soil type and the importance factor of the bridge under study according to Eurocode 8 Part 2.

3.2. Step 2: Decision Process

Initially, the software performs a compression check for bearing compression (σ_e) were a minimum of 2.0 Mpa and a maximum value of 5.0 Mpa are proposed by the system itself according to Abe et al., (2004). The software proceeds with the Eurocode's 8 - Part 2 Shear strain checks. All the bearings that passed the above initial screening process are checked against a set of code-prescribed criteria, involving the normalized shear strain of the bearing because of (a) seismic loading, (b) vertical loading and (c) rotation. For this paper, the criterion prescribed in Eurocode 8 is adopted, according to which the maximum total shear strain $\varepsilon_{t,d}$ of the equivalent single degree of freedom system of the seismically isolated bridge should not exceed:

$$\varepsilon_{t,d} \leq 6.0 \tag{1}$$

where:

$$\varepsilon_{t,d} = \varepsilon_{s,d} + \varepsilon_{c,d} + \varepsilon_{a,d} \tag{2}$$

and $\varepsilon_{s,d}$ is the shear strain due to the total design seismic displacement, $\varepsilon_{c,d}$ is the shear strain due to compression and $\varepsilon_{a,d}$ is the shear strain due to angular rotation. The second criterion (Eurocode 8 - Part 2) is that the seismically induced shear strain $\varepsilon_{s,d}$ should be limited to:

$$\varepsilon_{s,d} \leq 2.0 \tag{3}$$

3.3. Step 3: Selection process of eligible bearings

Having applied the above set of criteria and screening processes related to the compression and total shear deformation checks, the eligible bearing sections (i) that have passed the above checks are then prioritized based on a combined cost-effectiveness criterion. In particular, the remaining bearings are ranked by the highest OP(i) (Optimal Performance) ratio, which corresponds to the highest safety criterion value that can be achieved for the minimum cost, namely:

$$OP_{(i)} = \frac{SC_{(i)}}{CC_{(i)}} \tag{4}$$

where SC(i) is a factor indicating the degree of compliance to the safety criterion incorporated in the code provisions as clearly stated by equation 2. The value for this safety criterion is derived for each eligible bearing (i) through the following formula as:

$$SC_{(i)} = \frac{\varepsilon_{s,\max(i)}}{\varepsilon_{s,d(i)}} \tag{5}$$

$\varepsilon_{s,max(i)}$ is in turn, the allowable (by these code provisions) maximum shear strain and $\varepsilon_{s,d(i)}$ is the predicted shear strain due to the total design seismic displacement. When this safety criterion has a value just larger than one (1.0) the compliance to this safety criterion is only just satisfied according to the code safety requirements, whereas when this value is larger than one (1.0) this compliance to the code safety requirements has a corresponding margin. Considering the cost of all bearing sections (i) that passed the safety criterion (equation 5), the minimum cost per unit bearing minFC(i) in equation 6 is the lowest item cost among all eligible bearings (that is, the ones that passed the compression and strain-based checks). CC(i) is the cost ratio for each bearing section that passed the safety criterion defined as:

$$CC_{(i)} = \frac{FC_{(i)}}{\text{min}FC_{(i)}} \tag{6}$$

where $FC_{(i)}$ is the corresponding final item cost of each bearing *(i)* expressed in Euro currency (€) that is approximated as:

$$FC_{(i)} = sc + V_{b(i)} \cdot c_v \text{ (in €)} \tag{7}$$

that is, as a function of the bearing volume Vb(i), the cost per unit volume c_v and the standard structural cost (sc) related to the bearing volume. A more refined formula for eq. 7 is proposed by Manos et al. (2011). Once the Optimal Performance, namely, OP(i), ratios are computed for each eligible bearing, all sections are ranked and the designer has a clear overview of the level of safety provided by the selection of each bearing normalized by its corresponding cost. Because all bearing sections that have passed the checks described in Step 2 are equally eligible in compliance with the

Eurocode 8 safety criterion provisions (see equation 5), it is the designer's decision to pick those bearings leading to the optimum performance, which means that an extra margin of safety can be gained with relatively minimal extra cost. The above methodology has been implemented in an interactive computer software as part of an expert system presented in the following.

4. PARTICULARS OF THE EXPERT SYSTEM

In what follows the particulars of this expert system will be described in a summary form. Full details are presented in Manos et al. 2011.

4.1. Structure of the data base.

The above decision-making system was integrated and implemented in a computer software to facilitate the process and visualize the results in a way useful to the designer. As already mentioned, a database of 260 bearings available on the international market is developed in Microsoft Access using three distinct relational tables containing the necessary fields to describe the bearing geometry and capacity.

4.2. User input.

The primary input of the software refers to Step 1 of the proposed methodology and is made through a user-friendly interface, which manages previous and new bridge seismic isolation alternative solutions as these are progressively created by the user. A new project, that is a new preliminary design of isolation system requires the following input parameters:

4.2.1 Selection of structural system

The software can be used for the preliminary design of the seismic isolation system of bridges up to four spans, as shown in Figure 1. The weight of the superstructure, which essentially controls the vertical load on the bearings, is either given by the designer as it is possible that the deck section has been selected before the selection of the isolation system or is estimated by the knowledge-based software for three typical deck types that are a box girder section, a voided-slab deck or a deck with precast and pre-stressed I-beams.

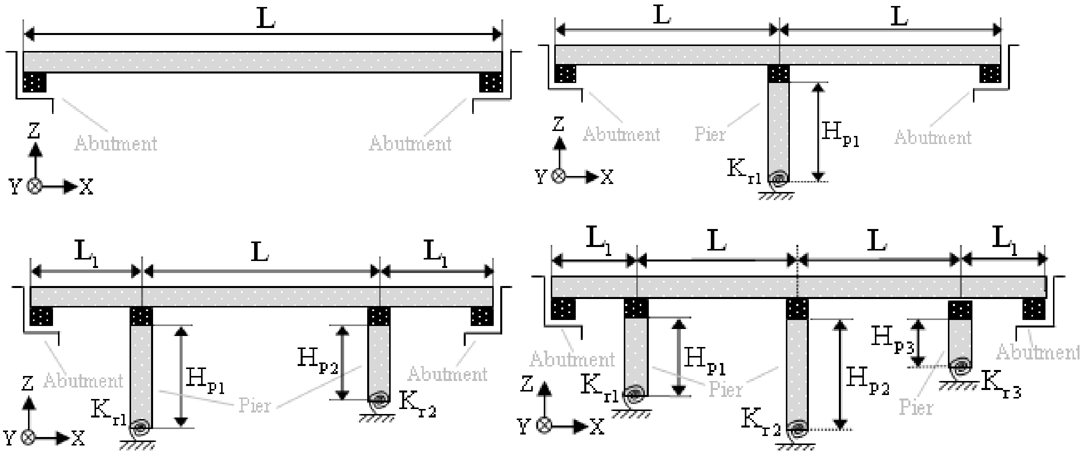

Figure 1: Typical bridge types (geometries) with: (a) one, (b) two, (c) three or (d) four spans

4.2.2 Desirable bearing type and configuration

The cross-section of the bearing (namely, rectangular or circular) can also be selected at this stage. With pre-stressed and precast I-beam bridge decks, the number of bearings on each support (pier or abutment) is based on the number of the longitudinal beams. In a cast-in-situ box girder or slab-type bridge deck, the number of bearings per support can be decided by the designer as a function of the dimensions of the pier's cap and the anticipated response of the isolated deck as well as using the software. The shear modulus of the bearings is automatically set by the program based on the manufacturer's specifications or any other experimentally justified value for the case of noncommercial bearings after appropriate testing, as described in Manos et al. (2011). It is noted that the value suggested by Eurocode 8 (Eurocode 8 Part 2, 2004) is 1.0 Mpa. Eurocode 8 also provides a lower and upper limit of 0.9 Mpa and 1.5 Mpa

4.2.3 Level of seismic demand

The user defines the level of seismic demand, based on the elastic response spectrum of Eurocode 8-Part 1, the relevant soil classification and importance factor and a peak ground acceleration of 0.16, 0.24 and 0.36; the latter being an open parameter to potentially comply with various levels of seismic hazard in other countries.

4.3. Decision Process.

The system automatically checks all bearings stored in the database against compression and the shear strains induced by the earthquake loading. These checks are based on the compression and shear strain criteria (Equations 1, 2 and 3) and then ranks all eligible bearings that have passed the above checks. The results are illustrated in a graph, of the OP(i) ratios (eqt. 4) with the bearing section geometry.

4.4. Assumptions and limitations.

The simplified analysis performed in the software considering the rigid deck model for the bridge, is applicable when the total mass of the piers is less than 20% of the total bridge mass, as prescribed by Eurocode 8. The bridges under design should also be straight or have small curvature in plan and small longitudinal inclination. The software can be used in all isolated bridges with low damping elastomeric bearings that are bearings with an effective damping not larger than 6%. However, the validity of the software for high damping rubber bearings (HDRBs) is being currently investigated. As already mentioned, the software is developed for the preliminary design of the isolation of bridges with up to four spans.

The flexibility of the foundation, the piers and the deck in both the longitudinal and transverse direction of the bridge was taken into account in the revised version of the software. The flexibility of the foundation is a user input for all the piers. The influence of the other two parameters (flexibility of the piers and the deck) were extensively investigated as described in the next sections of the paper.

Another assumption of the software concerns the bearings used for the support of the deck to the piers and abutments. The software can consider several bearings per support either the same or different number of bearings on each pier or abutment-support. This number has no limit because of the calculation procedure used in the software. The software, however, considers that the bearings are all the same type, for example, they have the same cross-section area and the same total thickness of the elastomeric layers along the deck.

Concerning the seismic action, the software considers that the bridge is isolated in both the longitudinal and the transverse direction of the bridge as the software deals with the simultaneous action of longitudinal and transverse earthquake motion. The response of the bridge in the transverse direction can be assumed to be restrained by seismic links, which join the deck with the piers' heads.

5. ADDITIONAL FEATURES OF THE EXPERT SYSTEM

In what follows additional features of this expert system will be described in a summary form. These features were not included in the previous work by Manos et al. 2011. They represent an extension of this work that has been completed recently.

5.1. The effect of piers' flexibility in the longitudinal direction

In the initial version of the software (Manos et al., 2011), an assumption was made that the flexibility of the piers is negligible when compared to the flexibility of the isolator units for horizontal seismic loads. In this section the flexibility of the piers in the longitudinal direction is examined. Five different pier sections with variable dimensions in-plan and four different pier heights were considered in this parametric numerical study. The pier sections represent typical cross sections that are employed in the design of medium span bridges. The expert system utilizes a relatively simple rationale to select certain geometry of the pier cross-sections, for each one of the given choices. The user also has the option to select for each pier cross-section the governing dimensions and the pier's height. In this parametric study the height of the piers was set to have values of 8, 10, 15 or 20 meters. The stiffness of the piers is in general considerably larger than the stiffness of the isolator system. The simplified approach for approximating the longitudinal stiffness of the piers that was incorporated in the expert system was checked by 3-D numerical simulations (Computers and Structures, SAP2002) of the pier-isolator-deck system which was subjected to horizontal forces applied in a static manner at the center of mass of the bridge deck. It was confirmed that this approximate methodology results in estimates of the horizontal displacements at the top of the piers that are in very good agreement with the corresponding pier deflections as predicted by the 3-D rigorous numerical simulations. The parametric numerical study covered a substantial number of bridge systems, with a variety of pier sections and with pier height ranging from 6 to 20 meters and bridge total lengths from 50 to 200 meters. By examining bridges that have all the other parameters the same and differ only as to the stiffness of the piers, e.g. by employing different pier sections, with different dimensions and different heights, thus with different longitudinal pier stiffness, the following conclusions were made. For the seismic force response, when the longitudinal stiffness of the piers is decreased the isolator bearing shear strain demands ε_s are increased. It was found from the examined cases (variation of the pier's height from 10m to 20m) that such a decrease in the pier's stiffness can lead to an increase of up to 18 % of the bearings' earthquake shear strain demand (ε_s).

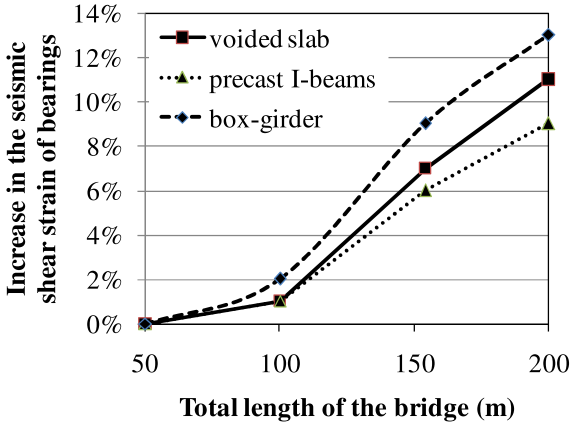

Figure 2: Increase of the maximum shear strain response of the isolator system when the flexibility of the deck in the transverse direction is considered.

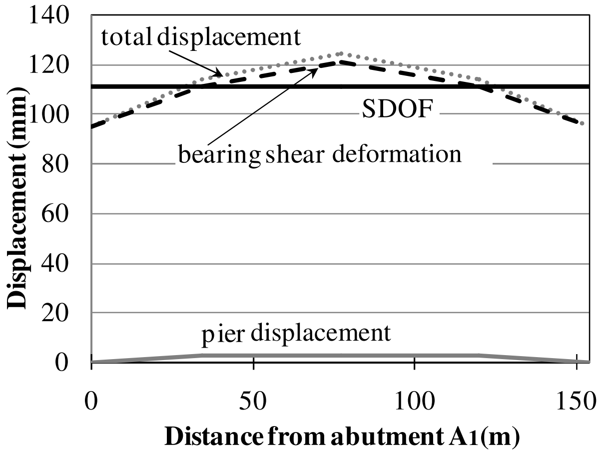

Figure 3: The response (displacements) in the transverse direction of the bridge when stiff piers are utilized in the transverse direction.

5.2. Flexibility of the deck considering the piers to be stiff

The influence of the flexibility of the deck on the design of the seismic isolation system was studied for four different deck lengths 50, 100, 150 and 200 meters and three different deck cross sections, (a) Box Girder Deck Section, (b) Voided-slab Deck Section and (c) Precast I beam Deck Section. The piers were considered to be stiff. The inclusion of the transverse flexibility of the deck results in eigen-period values of the isolated bridge system in the transverse direction, as predicted by the 3-D numerical model, up to 3% larger (for total deck length 200 meters) than the corresponding values resulting from the S.D.O.F. approximation, which forms the basis of the expert system. The influence of the deck's flexibility in the transverse direction on the maximum shear strain response of the isolation system is depicted in Figure 2. The increase of this maximum shear strain response is shown in this figure for three distinct deck systems; these are (a) Box Girder Deck Section, (b) Voided-slab

Deck Section and (c) Precast I beam Deck Section. For all three deck systems the total deck length is varied from 50m to 200m. As can be seen, the increase in the maximum shear strain response of the isolation system for a box girder deck section with 200m total length reaches approximately 13% compared with the corresponding maximum shear strain response of the isolation system of the same bridge where this deck flexibility is ignored. As expected, this influence decreases rapidly, for total deck lengths smaller than 150m (e.g. up to 2% for total length 100m, irrespective of the type of deck). Moreover, this influence also becomes smaller when the deck is a "Voided-slab Deck Section" (11% for 200m) than a "Box Girder Deck Section" (13% for 200m); in turn this influence becomes even smaller when a "Precast I beam Deck Section" is considered (9% for 200m). Hence, it is proposed to amplify by 13% the maximum shear displacement response found by the initial version of expert system, which is based on the S.D.O.F. approximation ignoring such deck flexibility influences. In this conservative way, the influence of most practical cases of deck flexibility in the transverse direction could be dealt with.

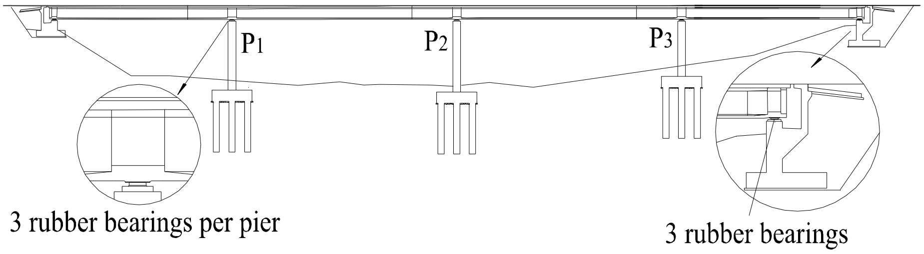

Figure 4: Longitudinal section of the simplified Arahthos-Peristeri Bridge.

5.3. Piers' flexibility in the transverse direction

The influence of the flexibility of the piers in the transverse direction on the maximum shear strain response of the isolation system is studied here. In this parametric study, five different pier types were considered, combined with two different bearing sections that were found by the initial version of the expert system to be the first two choices. The flexibility of the deck in the transverse direction, which was examined on its own in the previous section, is also included here. From a large number of numerically simulated cases the results from two distinct cases are discussed next. The transverse displacement response is studied for a box-girder bridge having a total length of 150m with either relatively flexible piers or relatively stiff piers in the transverse direction; this is plotted in figure 3 for the case of relatively stiff piers in the transverse direction. The 3-D simulation predicted displacement response at the top of the piers and the abutments is plotted in this figure with the solid grey line (pier displacements), whereas the displacement of the deck in the same locations is plotted with the dotted line. The shear displacement response of the isolators in these locations is plotted with the dashed line whereas with the solid black line is plotted the shear displacement response of the isolators for a system where the transverse flexibility of the piers is ignored. The latter values are predicted by the S.D.O.F. approximation included in the initial version of the expert system. The following observations can be made on the basis of these results:

- As can be seen in Figure 3 for the case of relatively stiff piers in the transverse direction, the resulting maximum shear displacement response of the isolator system in this case, when the flexibility of the piers in the transverse direction is considered, is larger than the corresponding values predicted by the S.D.O.F. approximation included in the initial version of the expert system. The shear displacement response of the isolators is mainly influenced in this case from the flexibility of the deck (see section 5.2) rather than the flexibility of the piers. The increase in the maximum shear displacement response is of the order of 9% in this case, as was already discussed in section 5.2. Hence, as already mentioned in this section, it is proposed to amplify by 12% the maximum shear displacement response found by the expert system, which is based on the S.D.O.F. approximation ignoring such deck flexibility influences. In this conservative way, the influence of most practical cases of deck flexibility in the transverse direction could be dealt with.
- For the case of relatively flexible piers in the transverse direction, the resulting maximum shear

displacement response of the isolator system in this flexible-pier case, when the flexibility of the piers in the transverse direction is considered, is smaller than the corresponding values predicted by the S.D.O.F. approximation included in the initial version of the expert system. The shear displacement response of the isolators is mainly influenced in this case from the flexibility of the piers rather than the flexibility of the deck, which was discussed in the previous section. The decrease in the maximum shear displacement response is of the order of 10% in this case. Thus, when the flexibility of the piers is ignored, as is the case in the S.D.O.F. approximation, the resulting choice of isolators is on the conservative side. Based on this finding no alteration of the S.D.O.F. approximation is proposed at this stage regarding the influences arising from the transverse flexibility of the piers.

6. VERIFICATION OF RESULTS FOR THE DESIGN OF A REAL BRIDGE

The methodology described above and the software developed were validated by extensive 2-D and 3-D parametric numerical simulations of bridges with the same geometry and structural system that can be selected through the options included in this software, as explained before. Moreover, this validation process was extended to include the case of a real bridge.

The bridge adopted as the case study is a simplified version of the Arahthos-Peristeri bridge described by Mitoulis et al., (2010), already constructed along the Egnatia Highway in northern Greece. The simplified system consists of four spans, that is the maximum number of spans that are supported by the software (Figure 4), as opposed to the six spans of the real structure, and a total length equal to 154.0 meters.

Three bearings were selected for supporting the deck on each abutment and pier to avoid extensive rejection of bearing sections due to high compression. The length of the central span is L=43.00 meters, the length of the end spans L_1=34.00 meters, the shape of the bearings is rectangular, soil type was taken corresponding to class B according to the Eurocode 8, the design ground acceleration was taken equal to 0.16g, the importance factor was assumed to be γ_I=1.30, the maximum allowable compression was set equal to 5.00 Mpa and the minimum compression to 2.00 Mpa, the shear modulus of the elastomeric bearings was assumed to be G = 1.0 Mpa and the deck mass was estimated as m = 308.40 KN/meter.

As described above, the validation procedure then followed two discrete steps. First, the effective period of the S.D.O.F. system was computed and was compared with more rigorous eigen-value analysis, with the aid of the finite element software SAP 2000 (Computers and Structures, 2002) as shown in Figure 5.

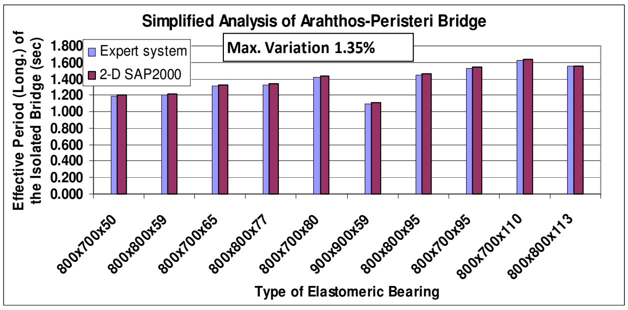

Figure 5: Comparison of the effective periods (T_{eff}) of the isolated bridge calculated by the software developed and by the more rigorous dynamic analysis with FE SAP 2000.

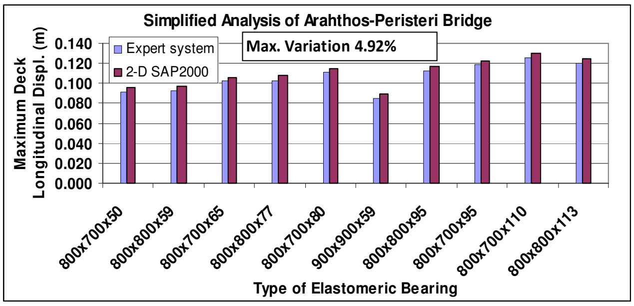

Figure 6: Comparison of the max. Deck displacement of the isolated bridge calculated by the software developed and by the more rigorous dynamic analysis with FE SAP 2000.

The validity of the S.D.O.F. assumption in the longitudinal direction for the particular bridge system was verified because the maximum deviation between the S.D.O.F. simplification and the fundamental period of the structure of the M.D.O.F. system did not exceed 1.4%, and this was deemed acceptable for preliminary design purposes. Next, the predicted by the S.D.O.F. approximation of the maximum deck horizontal seismic displacement response is compared with the corresponding values obtained through the more rigorous numerical analysis, as shown in figure 6. Again, the validity of the S.D.O.F. approximation for this particular bridge is verified because the observed differences between the corresponding values did not exceed 4.9%. For both figures 5 and 6 the dimensions of each bearing are plotted in the abscissa (namely, rectangular bearings with dimensions B_x, B_y and thickness of the elastomer t_e, e.g. equal to 800, 700 and 50 millimetres respectively)

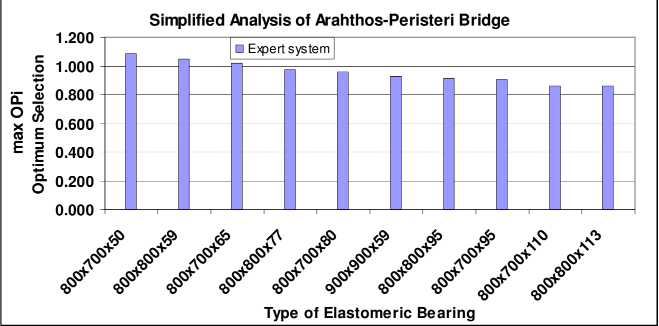

Figure 6: Bearings that passed the software tests. Plotted are the values of Optimal Performance ratio

The application of the methodology as implemented through the software of the expert system, resulted in 29 design alternatives (namely, eligible bearing sections) for the isolation system of the bridge that were all acceptable, namely, corresponding to a safety criterion value greater than one (1.0) as defined by equation 5. To facilitate the final choice, the first ten (10) of these eligible bearings are plotted in figure 5 according to the value of the Optimal Performance ratio, OP(i), as defined by equation 4.

The bearing with the highest value of this ratio is plotted at the further left of this plot. Consequently, the choice of such an "optimum" bearing scheme will be the one with the highest Optimal Performance ratio value. This choice is not based on the minimum cost, which, however, is indicated separately by the cost criterion values (CC(i)) (see equation 6), if the designer prefers to base his choice on the cost rather than the optimal performance. All the bearing schemes offered as designer's choice comply with the safety code requirements, described by Eq. 5.

CONCLUSIVE REMARKS

- The expert system developed for the preliminary design of the seismic isolation of bridges, assumed to respond as S.D.O.F. systems, is presented and discussed in this paper. The proposed methodology is based on the current design provisions of Eurocode 8. The methodology of this expert system is also implemented in software whose efficiency is validated through more rigorous 2-D and 3-D M.D.O.F. parametric numerical analyses as well as by using the case of a real bridge.
- It is evident that the prediction success of the preliminary design process, that is proposed here, heavily relies on the extent of the contribution of the fundamental mode in the longitudinal direction, which, when dominant, yields the S.D.O.F. simplification as reasonable assumption.
- The initial version of the expert system did not include any influence arising from either the flexibility of the piers in the longitudinal or transverse direction or the flexibility of the deck.
- The current investigation revealed that by not accounting for the flexibility of the piers the expert system predictions of the maximum shear strain response of the isolators is on the conservative side by a small margin and as such these predictions can be considered satisfactory.
- On the contrary it was found that the contribution of the flexibility of the deck maximum on the maximum shear strain response of the isolators cannot so easily be neglected. Hence, it is proposed to amplify by 13% the maximum shear displacement response found by the initial version of expert system, which is based on the S.D.O.F. approximation ignoring such deck flexibility influences. In this conservative way, the influence of most practical cases of deck flexibility in the transverse direction could be dealt with.
- The software that is based on this expert system permits the investigation of hundreds of bearing solutions. The eligible bearing hierarchy provided through the proposed safety over cost (Optimal Performance) criterion, provides a significantly large number of potential design alternatives to be considered for the final selection. In this way, the proposed process can be seen as an effective preliminary design tool, believed to lead to the quicker and more reliable estimate of the optimal bearing selection and seismic response of bridges, assumed to respond as S.D.O.F. systems, either in the stage before its final design or when such an existing bridge is checked for upgrading its seismic performance using such an isolation scheme

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