TESTS AND IMOROVEMENT OF BRIDGE ELASTOMERIC BEARINGS AND SOFTWARE DEVELOPMENT FOR THEIR PRELIMINARY DESIGN

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ABSTRACT:

The present paper focuses on both existing and new R/C bridge overpasses and aims at a) the design and pilot production of elastomeric (steel-laminated) bearings, specifically by a local Hellenic industry, which then can be used in practice, b) the investigation of the mechanical properties of these pilot bearings at the Laboratory of Strength of Materials of Aristotle University and c) the development of a an expert system which can link the produced elastomeric bearings as well as same type bearings that are usually employed with the current design practice in the selection of an appropriate elastomeric bearing scheme for typical R/C bridge overpasses in Greece. Along these lines a series of tests were performed on unit slice specimens of properties and dimensions representative of the pilot bearings. Summary results are presented in this paper of the aforementioned ongoing experimental investigation along with the measured mechanical characteristics under standard loading sequences. Numerical simulations are performed for validation processes for the development of the expert system based on the Greek Guidelines for the design of bridges with seismic isolation and Eurocode 8- Part 2 Annex for the design of bridges. Summary information of this expert system is presented herein; it is aimed for selecting, during preliminary design, a set of 'optimal' bearings from a database of commercially available ones, inclusive the foreseen pilot production. This selection process is based on the criteria set by the Greek Guidelines for seismic isolation, engineering judgment as well as on international standards. It is believed that the above described scheme can contribute towards a better link between production that is based on local industries and needs, experimentally-based optimization and final seismic design of bridge structures.

KEYWORDS: Seismic isolation, highway overpasses, elastomeric bearings

1. INTRODUCTION

The main objective of this research is to provide tools for helping design relatively simple bridge structures as highway overpasses with the emphasis being on their earthquake performance and the inclusion in their design of elastomeric bearings. This objective addresses both new and existing structures in an effort to upgrade their earthquake performance (Calvi and Pavese, 1998, Dolce and Marnetto, 1998, Priestley et.al. ,1996) and is motivated by the fact that during the last decade, a large road network has been constructed in Northern Greece with more than 646 bridges built of a total of 40km length (Panetsos and Konstantidis 2003). These are structures of relatively small dimensions (i.e. L<100m) and their most common structural configurations are depicted in Figures 1 and 2. Along these lines, the application of seismic isolation in the design of new bridges or for the upgrade of the existing, older bridge structures has attracted scientific attention (Naeim and Kelly 1999). This increasing interest is also reflected, among other actions, on the research conducted in the framework of the Regional Innovation Pole (RIP) of the Region of Central Macedonia, in Northern Greece which was established in 2006, in the city of Thessaloniki. This particular research framework focuses on both existing and new R/C bridge overpasses, which represent the majority of the bridge stock, and aims at a) the design and pilot production of elastomeric (steel-laminated) bearings, specifically by a local Hellenic industry, which then can be used in practice, b) the investigation of the mechanical properties of these pilot bearings at the Laboratory of Strength of Materials of Aristotle University and c) the development of a an expert system which can link the produced elastomeric bearings as well as same type bearings that are usually employed with the current design practice in the selection of an appropriate elastomeric bearing scheme for typical R/C bridge overpasses in Greece.

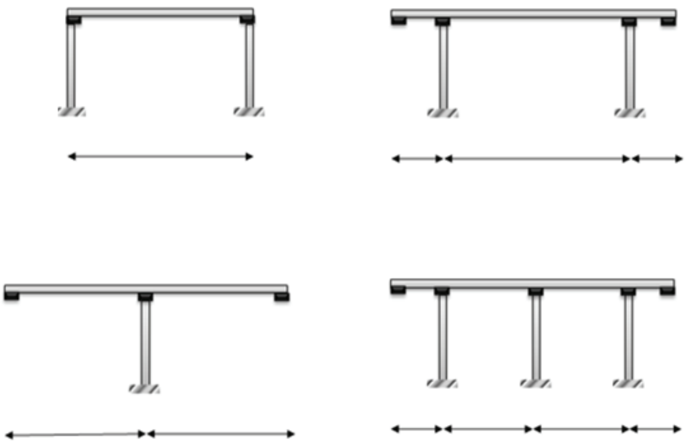

Figure 1. Overpasses with 1,2,3 and 4 spans

In this framework, a series of tests were performed on unit slice specimens of properties and dimensions representative of the pilot bearings. Summary results are presented in this paper of the aforementioned ongoing experimental investigation along with the measured mechanical characteristics under standard loading sequences. Numerical simulations are also performed for validation processes and an expert system is developed based on the Greek Guidelines for the design of bridges with seismic isolation as well as on the Eurocode 8- Part 2 Annex for the design of bridges. Summary information of this expert system is presented herein; it is aimed at selecting, during preliminary design, of a set of 'optimal' bearings from a database of commercially available ones, inclusive the foreseen pilot production. This selection process is based on the criteria set by the Greek Guidelines for seismic isolation, engineering judgment as well as on international standards. It is believed that the above described scheme can contribute towards a better link between production that is based on local industries and needs, experimentally-based optimization and final seismic design of bridge structures.

Figure 2 Typical bridge overpasses in Greece

2. MECHANICAL CHARACTERISTICS OF ELASTOMERIC BEARINGS

An experimental investigation was carried out aiming at establishing the mechanical characteristics of elastomeric bearings locally produced. For this purpose a series of standard tests were performed at the Laboratory of Strength of Materials and Structures of Aristotle University according to the International Standard ISO 22762-1 (2005). Initially, these tests were used as qualification tests for the materials used in the production; that is the neoprene, the steel plates and the adhesion materials and processes. These tests are presented in a summary form and discussed in what follows. Next, in an effort to study the influence of certain parameters in the mechanical characteristics of these elastomeric bearings, the vulcanization process was investigated and in particular influence of the time duration in the mechanical characteristics of the final product. Thus, a set of specimens were produced and tested with their vulcanization lasting either 15minutes or 25 minute.

2.1. Tensile cyclic tests of the neoprene

Eleven tests were performed with frequencies varying from 0.25Hz to 4.0Hz. At the end of the series the specimens failed at maximum axial strain 400% and maximum axial stress 8Mpa. At fracture the specimen underwent approximately 500 cycles. The approximate Young's modulus was found to be equal to 0.75Mpa. At high levels of axial strain (more than 100%) this value was more than double. At even higher levels of strain this value was further increased. At the initial static–load-unload cycles there was a considerable difference in the load-unload path that tended to become less pronounced when the loading cycles increased in numbers. There

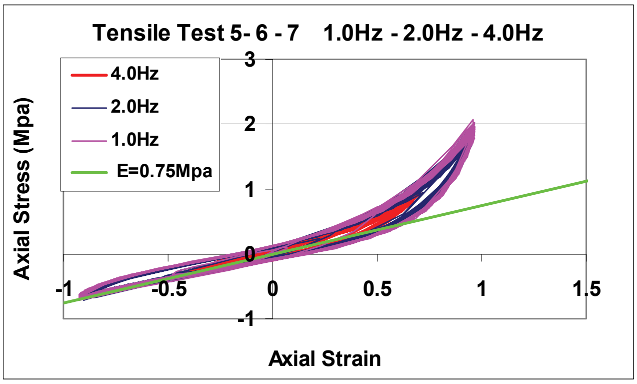

Figure 3. Tensile cyclic tests with 200% strains.

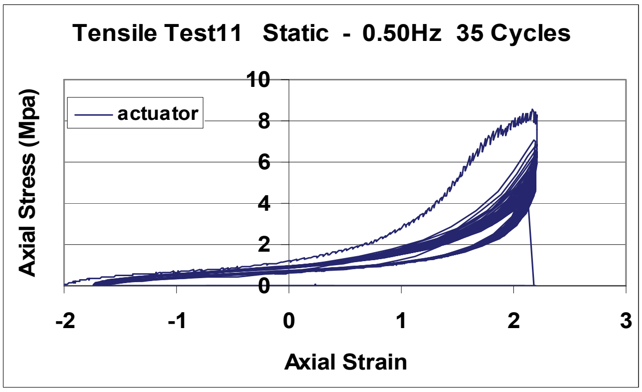

Figure 4. Tensile cyclic tests with 400% strains that lead to the fracture of the specimen

was no noticeable influence on the behaviour of the specimen arising from the frequency of the loading. The cyclic loading was introduced from an initial condition that was the result of preloading it with 50% of the target maximum strain level. Figure 3 depicts the test results for maximum target strain 200% whereas figure 4 depicts similar results for maximum target strain 400% which resulted in the fracture of the test specimen.

2.2. Shear cyclic tests of unit slices of elastomeric bearings.

Shear cyclic tests of a specimens made of two unit slices were performed according to the International Standard ISO 22762-1 (2005). Each unit slice included a layer of elastomer and two steel plates from a bearing with plan dimensions 200mm x 200mm. The dimensions of each slice of elastomer were 200mm x 200mm and 7.62mm thickness. Thus, the tested specimens were formed by two slices of elastomer and four steel plates. Each steel plate had a thickness of 2.94mm and dimensions in plan of 200x200mm. Figure 5 depicts the used loading arrangement. The final specimen was of relatively large dimensions as to be in plan a one to one representations of elastomeric bearings produced by the same process; that is employing identical unit slices and building it up at the desired height with the appropriate number of such unit slices (Abe, Yoshida and Fujino, 2004). A dynamic actuator of considerable displacement and force capability was utilized to introduce a series of cyclic shear strain imposed loading sequences to the specimens (see figure 5). Initially, the series of tests did not exceed a maximum strain level of 100%. Next a series of similar tests introduced maximum shear strain levels larger than 100% up to the failure of the specimen that appeared in the form of unbonding of the elastomer from the steel plating. Apart from test specimens with the above dimensions, additional tests were also performed that corresponded to cylindrical elastomeric bearings having as plan dimensions of each slice of elastomer a diameter of 250mm with 7.62mm thickness. These specimens were produced with the same process mentioned before. In what follows typical tests results are presented in brief.

Throughout all the tests the applied load producing the shear strains was monitored together with the corresponding displacements of the specimen that were utilized to deduce the applied shear stress and shear strain levels to the specimen. At the same time the applied vertical load, normal to the slices of neoprene, was recorded and checked for any significant variations; the objective in this case being to keep the vertical load almost constant at the range of 2.0 to 2.5 Mpa throughout all tests.

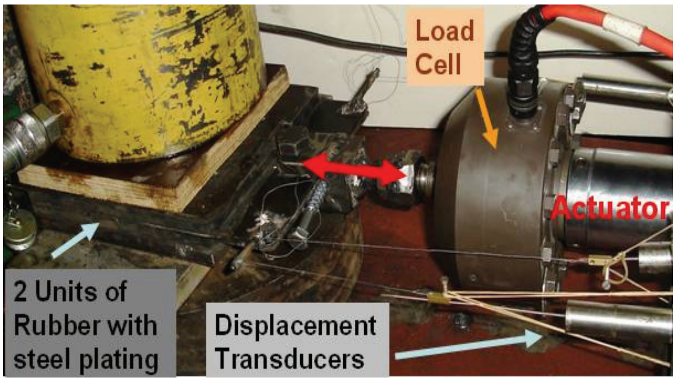

Figure 5. Loading arrangement of a unit slice.

2.2.1. Shear cyclic tests with strain amplitude lower than 100%

These cyclic tests were performed for the following combinations: 3-11 cycles for each test, with temperature 23 degrees Celsius and cyclic loading varying with frequency 0.2Hz . The shear strain amplitude was varied from 5% to 75% in the following steps: 5% (0.38mm), 10% (0.76mm), 25% (1.91mm), 50% (3.81mm), and 75% (5.72mm). The corresponding results for the *initial* shear tests are depicted in figure 6. An increase in the shear stiffness was observed when the cyclic shear strain became larger than 75%. *Subsequent* tests that followed the initial tests with shear strain amplitudes varying again in the range from 5% to 75% exhibited an increase in the shear stiffness when they are compared with the results of the initial shear tests (figure 7). Again, the specimen exhibited a stable performance throughout the increasing shear strain amplitude from 5% to 75% during these subsequent tests.

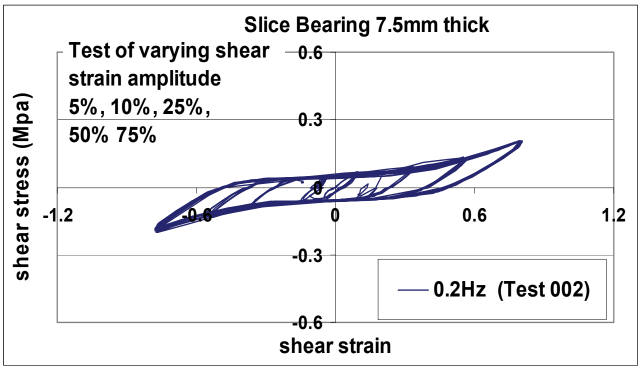

Figure 6. Initial shear cyclic test results for frequency 0.2Hz and shear strain amplitude from 5% to 75%

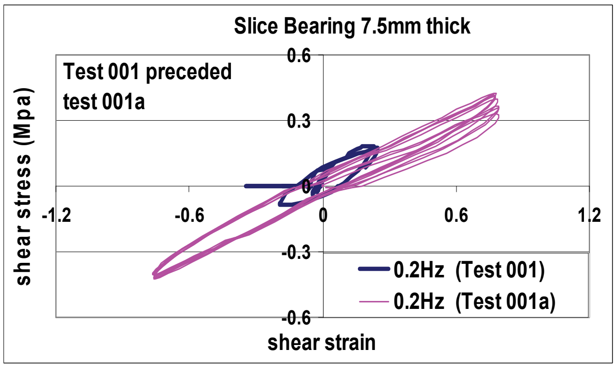

Figure 7. Subsequent shear cyclic test results for frequency 0.2Hz and shear strain amplitude from 5% to 75%

Additional tests were also performed with the same specimens whereby the studied variable this time was the frequency of imposing the shear strain, keeping the maximum target strain amplitude constant and equal to 75%. The corresponding results are depicted in figure 8. In this case the specimen's performance was examined for loading frequencies equal to 0.1Hz, 0.5Hz and 1.0Hz. As can be seen from this figure no significant variation in the performance of the specimen could be observed from the obtained response whereby the loading frequency was varied from 0.1Hz to 1.00Hz.

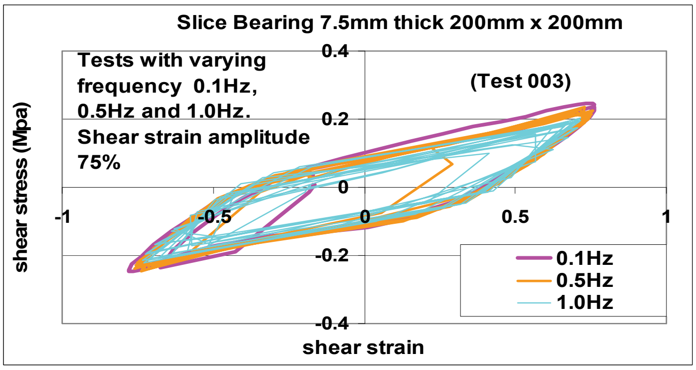

Figure 8. Shear cyclic test results for shear strain amplitude 75% and frequencies 0.1Hz, 0.5Hz and 1.0Hz

An additional specimen of the same geometry and produced by the same process was tested by the loading arrangement shown in figure 9. This time, apart from imposing the shear strain levels of continuously increasing amplitude, the specimen was placed under a constant compressive stress field normal to the horizontal plane of the elastomer. This stress field corresponded to an equivalent compressive stress equal to 2.4Mpa. The frequency of the cyclic load was equal to 0.5Hz and the shear strain amplitude was continuously increasing from 10% to 75%. The summary results of this test are depicted in figure 10. As can be seen by comparing the results of figure 7 with those of figure 10 an increase in the stiffness and a decrease in the equivalent damping ratio is evident when the specimen is subjected to the previously described compressive stress field of 2.4Mpa equivalent uniform stress normal to the elastomer. However, this observation should not be generalized; as was shown from the measurements of another investigation (Ryan et. al. 2004, Manos et. al. 2007) further increase in this compressive stress field has the opposite effect, that is a decrease in the shear stiffness and an increase in the equivalent damping ratio.

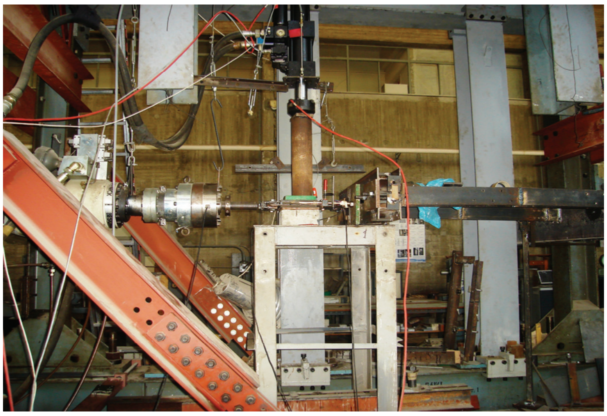

Figure 9. Loading arrangement of a unit slice with the simultaneous application of a compressive stress field.

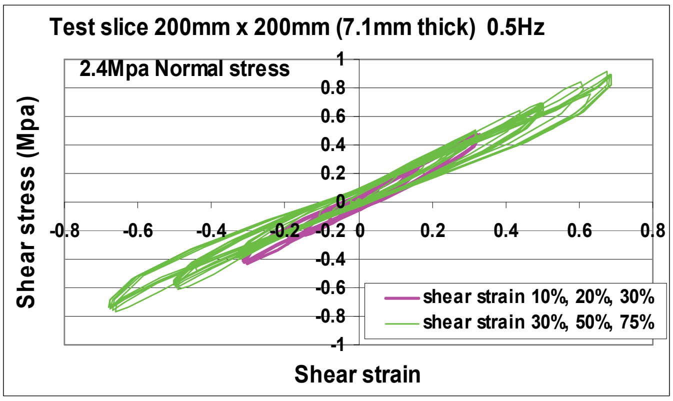

Figure 10. Shear cyclic test results for frequency 0.5Hz and shear strain amplitude from 5% to 75% slice with the simultaneous application of a compressive stress field.

2.2.2. Shear cyclic tests with strain amplitude higher than 100%

The previously described loading sequences were repeated again with unit slice specimens being loaded this time with shear strain amplitudes higher than 100% up to the failure of the specimen. Two distinct loading arrangements were again adopted.

First, the shear strains were introduced without the application of compressive load normal to the horizontal plane of the elastomer (figure 11a) whereas in the second case a vertical load was applied and kept constant producing an equivalent uniform compressive stress normal to the plane of the elastomer (figure 9) in the range of 2.0 to 2.5 Mpa. Figure 11b depicts the failing mode of the specimen during this loading process without the presence of the compressive stress field. Figure 12 depicts the results of this test with large shear strains with the application of compressive normal stress, whereas figures 11b and 13 show the resulting unbonding of the elastomer from the steel plating at the end of this loading sequence. The load-unload behavior of this specimen is shown in figure 12 for levels of shear strain starting from 100% and gradually increasing to 275%.

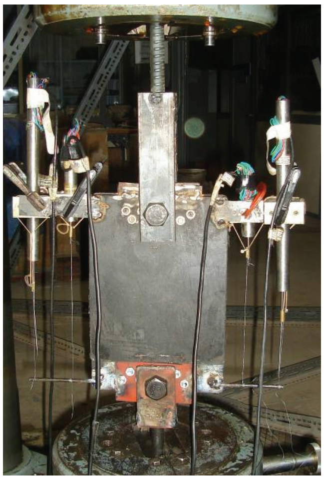

Figure 11a. Loading the unit slice specimen without the presence of the compressive stress field.

Figure 11b. Failing mode of the unit slice specimen without the presence of the compressive stress field.

It can be observed that for shear strain levels lower than 200% the specimen's behavior remains stable even for this demanding test that corresponds to an elastomeric bearing that does not have the beneficial stabilizing effect of the compressive stress field normal to the slices of the elastomer within the bearing. The maximum capacity reached for this specimen was equal to 1.7Mpa; this occurred for a maximum strain level equal to 275%. The load-unload behavior of the specimen with the simultaneous application of continuously increasing shear strains and an imposed compressive stress field normal to the elastomer equal to 2.4Mpa is shown in figure 14. The drops of stress that can be observed in this plot are due to the relaxation of the elastomer during small duration stops in the loading sequence. The levels of shear strain reached 230% during the first loading cyclic; then they were gradually increased to 300% whereby the maximum bearing capacity equal to 2.0Mpa was reached for this specimen. It can be observed that for shear strain levels higher than 300% the specimen's bearing capacity degrades; however this degradation does not progress rapidly; for shear strain levels 350% the specimen exhibits

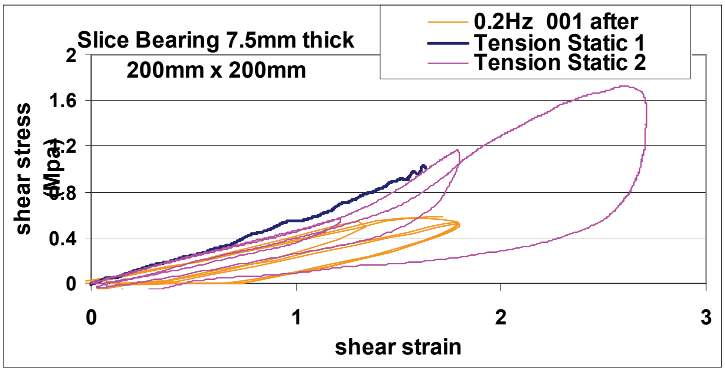

Figure 12. Large shear strains test without compressive normal stress

Figure13. The unbonding of the elastomer from the steel plating at the end of this loading sequence.

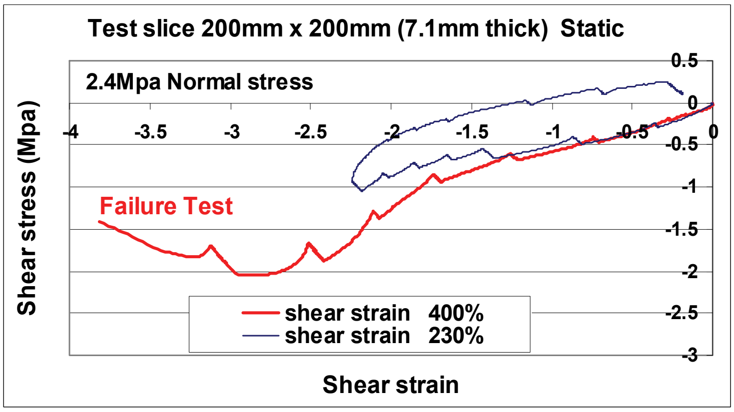

Figure 14. Large shear strains test with compressive normal stress

Figure 15. Failing mode of the unit slice specimen without the presence of the compressive stress field.

a bearing capacity almost equal to the maximum bearing capacity of the specimen the shear strains were introduced without the application of compressive load normal to the horizontal plane of the elastomer.From the comparison of the performance of the specimens with and without the compressive stress field (figures 14 and 12) it can be seen that the most severe test is that without the normal compressive stress field. It corresponds to an elastomeric bearing that does not have the beneficial stabilizing effect of the compressive stress field normal to the slices of the elastomer.

3. DEVELOPMENT OF AN EXPERT SYSTEM FOR THE PRELIMINARY DESIGN OF ELASTOMERIC BEARINFS FOR TYPICAL BRIDGE OVERPASS IN GREECE.

In what follows an outline of an expert system that was developed in the framework of this research investigation will be described. This expert system aimed to become a design tool for professionals in their preliminary stages of selecting an appropriate and cost-effective scheme of elastomeric bearings that could be applied in existing or new overpass bridges with typical structural forms and geometry in the Greek highway system. One of the main criteria for selecting such a scheme of elestomeric bearings is that it has to meet the requirements posed by the Guidelines for the design of bridges with seismic isolation (2004) in Greece, especially those safeguarding the satisfactory seismic behaviour of the structure.

3.1. An electronic database for the performance-based selection of bridge bearings

Within the framework described in the introduction and depending on (a) the period of construction and the corresponding seismic code used, (b) the pier type and cross-section, (c) the deck type and (d) the pier-deck connection, the selected bridge overpasses have been classified appropriately (Manos et al., 2007). Similar classification has also been performed for all bridges of the Egnatia Highway in Northern Greece (Kappos &

Moschonas, 2006). Furthermore, an electronic database has been developed specifically for overpasses and commercially available bearings that can be used in design and construction. Numerous geometrical (rubber and steel plate thickness, height, width and type) and material (shear modulus, maximum strain) data, have been archived for each (circular or rectangular) bearing. An expert system has also been developed capable to perform the selection of seismic isolation devices among the ones stored in the inventory. In particular, an interactive and user-friendly environment has been developed that elaborates the engineer to define the structural configuration of the overpass bridge and its corresponding seismic exposure. The later is based on the current Hellenic Seismic Code (EAK2000) and the specific guidelines for Seismic Isolation in Greece. Having decided (Figure 1 and figure 16) the type of overpass (in terms of number of spans, span and total length and locations of bearing-type pier-deck connections), the bridge class (in terms of number of lanes per direction), the number of bearings at each support, the preferred bearing shape and the parameters that define seismic loading (soil classification, seismic zone, importance category), the system automatically passes all bearings available in the database through a sequence of checks in order to filter out those that do not comply with the design criteria set. This staged filtering process which is illustrated in Figure 17 is essentially broken down into two major checks, in order to ensure that the bearings satisfy particular criteria related to their maximum compression and seismic deformation according to the aforementioned guidelines. The two main relationships that control this performance are:

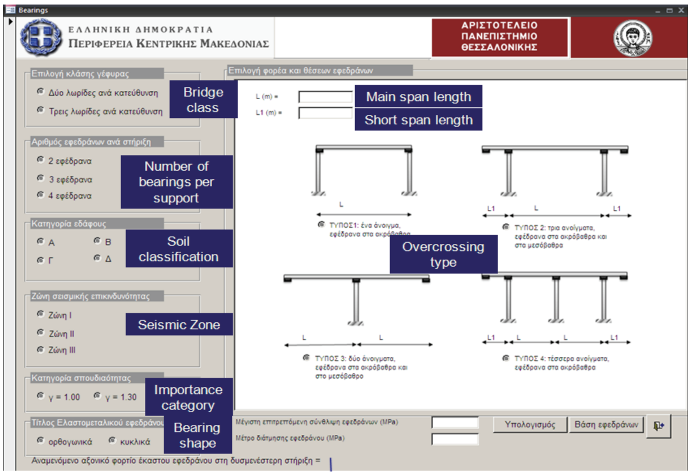

Figure 16. Software interface for selecting the input data

$$\varepsilon_{sd} = \frac{d_{Ed}}{\sum t_i} \qquad \varepsilon_{sd} < 2.0 \qquad (1)$$

$$\varepsilon_{b,d} = \varepsilon_{s,d} + \varepsilon_{c,d} \leq 6.09 \qquad (2)$$

where $\varepsilon_{s,d}$ the calculated maximum shear strain for the elastomeric bearing scheme due to the design horizontal earthquake and $\varepsilon_{c,d}$ the calculated maximum shear strain for all the design vertical actions. Once a set of bearings is found to meet the above criteria, the system automatically rates and ranks them using an 'optimal performance' (*OP*) criterion which aims at quantifying the relative safety that provides each bearing given its actual cost. This factor is expressed in the form of the following equation:

$$OP = SF / CC \qquad (3)$$

where *SF* is the safety factor provided based on the deformation criteria, mentioned above, set by the particular guidelines and *CC* is the relative cost of each bearing compared to the cost of the less expensive bearing from the ones that have passed

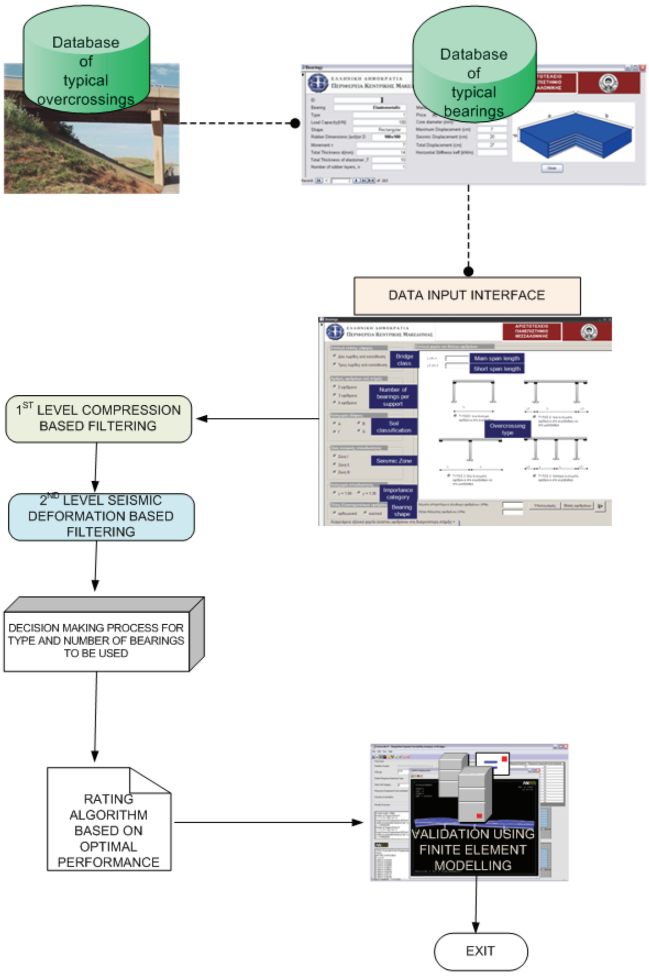

Figure 17. Overview of the program flow for evaluating the bearing performance

the filtering process successfully. Currently an effort is made to validate the system developed using more refined finite element analyses as a means to further increase the accuracy of the particular filtering process.

4. SUMMARY AND CONCLUSIONS

- A series of qualification tests were performed for unit slice specimens of elastomeric bearings produced by a local Greek manufacturer.
- From these tests the stable performance of the testes specimens cane be demonstrated for shear strains beyond the range of 200% with or without the simultaneous imposition of a compressive stress field normal to the plane of the elastomer.
- The presence of a relatively mild compressive field is beneficial as it extends the stable behaviour of the tested specimens for shear strain amplitude up to 300%. Moreover, for shear strain levels higher than 300% the specimen's bearing capacity degrades; however this degradation does not progress rapidly.
- From the test results with frequencies ranging from 0.2Hz to 1.0Hz it was demonstrated that the stable performance of the tested unit slice specimens was not affected by the frequency of the imposed cyclic shear strain loading.
- An expert system was developed aimed to become a design tool for professional in their preliminary stages of selecting an appropriate and cost-effective scheme of elastomeric bearings; this expert system could be applied in existing or new overpass bridges with typical structural forms and geometry in the Greek highway system.
- One of the main criteria within this expert system for selecting a scheme of elestomeric bearings is that it has to meet the requirements posed by the Guidelines for the design of bridges with seismic isolation (2004) in Greece, especially those safeguarding the satisfactory seismic behaviour of the structure.

Acknowledgements
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