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SEISMIC RESPONSE CONTROL OF A CANTILEVERED HIGHWAY SIGN SUPPORT, USING A TMD

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ABSTRACT

This work contributes to a better understanding of the seismic response of cantilevered sign support structures, used in highways. For such, the present paper presents a comparative study of the seismic response of a cantilever sign support, when subjected to earthquakes with and without a tuned mass damper (TMD). The paper starts with a brief summary of different methodologies, to assess seismic input on structures. Some guidelines on the considered procedure, for the selection of appropriate suites of accelerograms, complying with Eurocode 8 prescription for Portugal (Faro) are presented. To mitigate earthquakes dynamic effects, the sign support structure can be equipped with a TMD, with proven efficiency, ease of application and modelling, for the out-of-plane vibration control of the sign support, in terms of displacements and accelerations reductions, when the structure is subjected to series of real accelerograms compatible with the earthquake scenario of Eurocode 8-1.

KEYWORDS: Seismic Response, Eurocode 8-1, Cantilevered Sign Support Structure, TMD

INTRODUCTION

As the present work intends to study the effectiveness of TMD, it is of major importance, to describe the seismic input in the time domain. The purpose is to compare the structural response with and without a theoretical implementation of the TMD. For that, linear elastic dynamic time history analysis will be conducted, which is also very useful, when dominant modes are closely spaced or for multiply supported structures (bridges), where higher modes are expected to be excited, due to the asynchronous nature of incoming seismic waves (Katsanos, 2010). Time-domain is prescribed in the majority of seismic codes around the world, as so in the Eurocode 8-1 (EC8-1) (CEN, 2004a).

The aim of this paper is to present a structural model of a cantilevered sign structure, in order to study the effect of real earthquake records and recommend passive control measures, to limit the structure response (by TMD). Highway sign support structures have been studied previously by the authors, in the viewpoints of stability and design, under (Paiva, 2013a) the Eurocode 3-1; moreover, some significant aspects of the wind response have also been addressed in other studies, by the authors (Paiva, 2013b). The following section pretends to detail the fundamentals of seismic-input selection on structures. Afterwards, the methodology, to address the selection of real accelerograms complying with EC8-1 is presented. A theoretical implementation of TMD will be studied, and a comparative analysis of the structure response (displacements and accelerations) with and without TMD will be made

RECORD SELECTION IN EUROCODE 8-1

The structural seismic assessment requires earthquake loads to be represented either by response spectrum or by recorded acceleration time histories (accelerograms) as input to a linear or non-linear dynamic analysis. For that, input motions have to be selected so as to represent regional seismicity and must conform to expected earthquake (target spectrum), this mean they have to fulfill earthquake scenarios (as EC8-1 describes) in order to be used in the posterior dynamic analysis.

Elastic Response Spectra of Faro According with EC8

Contrary to general practice, the Portuguese National Annex of the EC8-1 adopts two zones (Figure 1), one for the near-source scenario and the other for a distant-source scenario. In the present work, Faro municipality has chosen for the location of the sign structure, because of the many studies available concerning its disaggregation seismic hazard. Faro is located in the south of Portugal, corresponding to zone 1.2 and 2.5 in Figure 1 (A1 and A2). In this study, and for the purpose of the TMD efficient assessment, only zone 1.2 will be study, which represent a severe earthquake and distant-source scenario.

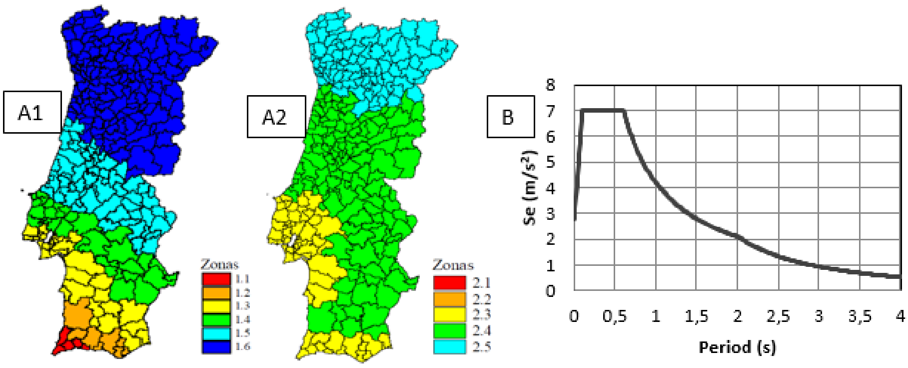

Figure 1: Seismic Zonation for Distant Scenario (A1) and for Nearby Scenario (A2) in the EC8 Portuguese National Annex. Colours Correspond to Different PGA Values and at each Site the Higher of the Two Values is Adopted. Elastic Response Spectrum for a Ground Type C in Faro, Zone 1.2 (Figure B)

In EC8-1 the seismic action on structures is defined after the acceleration elastic response spectrum. In Part 1, which applies for buildings, the spectral shapes are given for both horizontal and vertical components of motion. All shapes have a functional form which depends, a part of the soil class; on a single value a_g, anchoring the spectrum to the seismicity of the site. The a_g refers to the seismic classification of the territory in each country; it is basically related to the hazard, in terms of peak ground acceleration (PGA) on rock, for the site.

Recurring to EC8-1 Portuguese national annex, the resulting ag for zone 1.2 is 2.0 m/s^2. Adopting a ground type C (S_{max}=1.6, with S=1.4) and all the periods, necessary to the construction of the elastic response spectrum, with TB=0.1, TC=0.6 and TD=2.0. The resulting elastic response spectrum (η=1.0), for Faro is represented in Figure 1 B.

Disaggregation of the Seismic Hazard for Faro

The Cornell approach to probabilistic seismic hazard analysis (PSHA) is based on an area summation, covering all the relevant sources (Cornell, 1968). Restricting the summation to a given sub-area, allows the estimation of the contribution of that sub-area, to the total hazard. This notion is the basis of the technique known as hazard disaggregation (Bazzurro, 1999), which allows the identification of the seismic sources, making dominant contributions to the hazard at a particular site. This information can in turn be used, to define the ground shaking scenarios (ex. magnitude and epicentral distance) that are relevant for earthquake risk mitigation at the site. Inadequate disaggregation of seismic hazard may be a distracting factor, focusing resources in sources that are not dominant and underestimate others.

Hazard disaggregation in Portugal (and Iberian Peninsula) was conducted in the works of (Sousa, 2009) and (Montilla, 2002) for example. Taking into account specific appreciations made in the paper of (Fonseca, 2012) the results of Montilla et al. were followed. In addition to that there is some information in the Portuguese National Annex EC8-1-5 (CEN, 2004b), which provide representative magnitudes for a return period of 475 years. For Faro municipality the magnitude adopted according with EC8-1-5 was 7.5, and a distance (mean value) of 123 km, this consists in a distant-earthquake scenario with scattered seismicity around the Gulf of Cadiz and West Cape San Vicente (as stated by Montilla et al., 2002).

Accelerograms Selection Rules According with EC8

Some issues or reasons can explain the difficulties experienced by common practitioners, in dealing with code-based record selection. According with Iervolino (2009), these issues can be grouped twofold: in the first one, the determination of the design earthquakes may require hazard data, often not readily available to engineers or may require seismological skills, beyond their education (as already mentioned); in the second group of reasons, the difficulties develop from matching a suite of real records to a design spectrum in a broad range of periods, which may be extremely unfeasible if appropriate tools are not available. The later situation has favored the use of spectrum matching accelerograms, either artificial or through manipulation of real records.

As it is generally recognized by many in the earthquake field, real records are considered the best representation of the seismic loading for structural assessment and design, so some computer aided tools have been developed for the record selection, as being that REXEL 3.5 (Iervolino, 2010), and other for spectral matching (Seismomatch, 2016).

The REXEL computer software allows to build design spectra according EC8-1 or to user-defined target design spectra, and to search for sets of 7, 14, 21 groups of records (each group may be made of 1, 2 or 3 components ground motions), from the European Strong-motion database (ESD) (Ambraseys, 2000) and (Ambraseys, 2004).

These sets are compatible to target spectra with respect to EC8-1 code prescriptions, but reflect also some seismological characteristics (Magnitude, epicentral distance and EC8-1 soil site classification), relevant for the seismic structural analysis. In the case of Seismomatch, the record selection must be made outside of the program, in Databases available online and posteriorly matched to the target spectrum.

Once, the reference spectrum has been defined, EC8-1 allows the use of any form of accelerograms for structural assessment; i.e., real, artificial or obtained by simulation of seismic source, propagation and site effects. To comply with Part 1 the set of accelerograms, regardless its type, should basically match the following criteria:

- A minimum of 3 accelerograms should be used;
- The mean of the zero period spectral response acceleration values (calculated from the individual time histories) should not be smaller than the value of ag S, for the site in question (S is the soil factor);

- In the range of periods between 0.2T1 and 2T1, where T1 is the fundamental period of the structure in the direction where the accelerogram will be applied, no value of the mean 5% damping elastic spectrum, calculated from all time histories, should be less than 90% of the corresponding value of the 5% damping elastic response spectrum.

The EC8-1, refers that in the case of spatial structures, the seismic motion shall consist of three simultaneously acting accelerograms representing the three spatial components of the shaking, then 3 of condition (a) shall be considered as the number of translational components of motion to be used (the two horizontal and the vertical one). Furthermore, the vertical component of the seismic action should be taken into account only for base-isolated structures, and for some special cases in regular buildings, if the design vertical acceleration for the A-type site class (a_{vg}) is greater than 0.25g. Finally, some prescriptions regarding duration are given for artificial accelerograms, and real or simulated records should be adequately qualified with regard to the seism genetic features of the sources and to the soil conditions appropriate to the site.

Section 4.3.3.4.3 of EC8-1, allows the consideration of the **mean effects on the structure**, rather than the **maximum**, if at least **seven nonlinear time-history analyses** are performed.

Iervolino (2008) investigated, whether it is possible to find unscaled real record sets fulfilling, as much as possible, the requirements of EC8-1. As a general conclusion it was found that prescriptions do not easily allow selecting suitable real record sets, factually favoring the use of records obtained, either by computer techniques or manipulation of real records, to have a spectral shape coincident to that of the reference in a broad range of periods.

The procedure for the selection of horizontal accelerograms, according with EC8-1 for the life safety limit state (475 years return period), involves the next 4 steps:

- Definition of the target spectrum, in this case the horizontal elastic response spectrum of Faro zone 1.2 (ground type C) that the set of records has to match on average. The present location demands the definition of two elastic response spectrum, zone 1.2 and 2.3, but was already mentioned, for Faro, the main earthquake hazard scenario correspond to a distant seismic source, so in this paper only zone 1.2 is studied.
- Definition of the magnitude and distance bins for each of the two target spectra referred for the specific site class. For the type 1 (high and moderate seismicity regions) target spectrum the magnitude considered was $7.3<M<7.7$ and $80<R<160$. The reason for selecting the parameters magnitude, source-to-site distance and site class, is that important characteristics of the record such as frequency content, spectral amplitudes, spectral shape, and duration are correlated with the mentioned parameters (Beyer, 2007). For their case study, Bommer, 2004 recommended a magnitude bin width +-0.20Mw and a distance bin +-40 km around the scenario value of 10 km, they recommend to relax the distance criterion if the search yields too few records. And in the case of insufficient records, they also suggest to be not too rigorous regarding the match of site class but to solely exclude records with very different site classification from that of the project site.
- Assigning the period range where the average spectrum of the set has to be compatible with the target spectrum and tolerances acceptable. For the present case a minimum period of 0.14 s ($0.2*T1\cong0.14$ s, where T1=0.7s is the fundamental period of the cantilevered sign support) and maximum period of 2.0 ($2*T1=1.4$ but a larger value was adopted), the lower and upper spectral matching limits were respectively 10% and 30 %. The EC8 explicitly

states that the average elastic spectrum must not underestimate the code spectrum, with 10% tolerance (lower limit), but does not provide any indication about the upper limit. Therefore, it is of economically importance to reduce as much as possible this overestimation of the spectrum, that's why the correspondent upper limit was chosen.

- Running the search for combinations of seven records with two horizontal components of motion (14 records) and that, on average, match the design spectrum with parameters specified in step 3. REXEL 3.5 allows to obtain combinations of accelerograms compatible with target spectrum which does not need to be scale, but also permits choosing sets of accelerograms compatible with target spectrum if linearly scaled. This means that the list of spectra defined in step 2 are preliminarily normalized dividing the spectral ordinates to their Peak ground acceleration (PGA). Combination of these spectra are compared to the non-dimensional code spectrum. This situation is for cases in which horizontal motion has to be applied in both direction of 3D structure, and where vertical acceleration can be ignored.

Accelerograms Selection for Faro

In the first search, none of the combinations available in the database complied with EC8 prescription, even with the scaled record option selected. So in the subsequent search all ground types were considered for the selection, hence, a total of 3 earthquakes (possible overrepresentation of some events) were found acceptable (with 2x23 records from different stations). The Figure 2 shows the 14 scaled records (7x e 7y) that are compatible with the EC8-1 target spectrum for Faro (zone 1). The program selects the records according with a parameter, which gives a measure how much the spectrum of an individual record deviates from the target spectrum of the code.

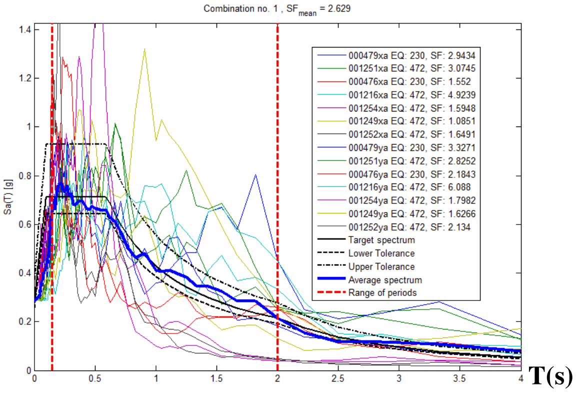

Figure 2: Results of the 14 Selected Records, Scaled Response Spectra and Target Spectrum

The average scale factor has 2.6, with a maximum 6.1 for the record 1216 in the y direction. The Figure 3 shows the 14 scaled accelerograms, 7 in the x direction (top) and 7 y direction (bottom).

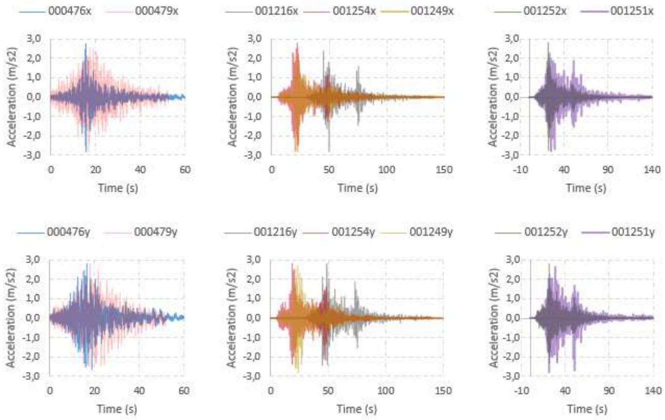

Figure3: Scaled Accelerograms, x Direction (Top Graphics) and y Direction (Bottom Graphics)

LINEAR DYNAMIC ANALYSIS OF A CANTILIVERED SIGN SUPPORT WITH AND WITHOUT TMD

Numerical Model Development and Modal Analysis

The Figure 4 represents a cantilevered sign support, constituted by a square hollow cross-section 250*250*8 mm (uniform member) in S355 strength steel. The column and the beam have a length of 6.5 m and 6.0 m, respectively. The signboard dimensions can also be seen in Figure 4. For in-depth information of the finite element model used in the dynamic analysis, the reader is referred to a paper from the authors (Paiva, 2013b). In the same paper, the reader can find the main results of the performed modal analysis.

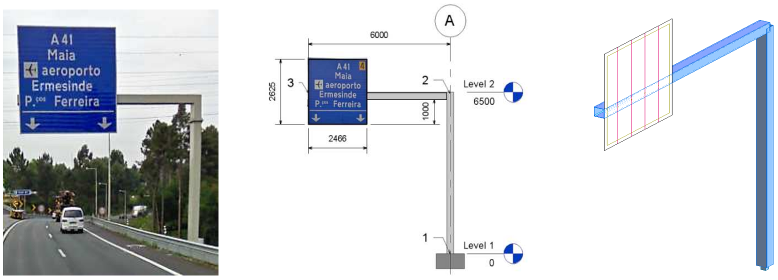

Figure 4: Example of a Cantilevered Sign Support Structure (Left) Geometry of the Design Example (Dimensions in mm, Center) and Numerical Model of the Cantilever Sign Support (Right)

Results from Time History Analysis with and without a TMD for Passive Control of Vibrations

The manner in which the two horizontal components of the accelerograms or ground motion (GM) are oriented when being applied to the structural model is extremely important and there is both little and inconsistent guidance on this aspect. In this work an original orthogonal orientation at 0º and then a 180º rotation of the GM was considered for the dynamic analysis (as indicated by the EC8-1).

The results in terms of displacements and accelerations were evaluated and compared for the computational structural model, without and with installed TMD vibrating bar. The Hilber-Hughes Taylor (HHT) method is used to solve dynamic equation of motion (with α=-0.3 for an unconditionally stable scheme of integration). The HHT method is a very efficient algorithm for numerical integration that allows removing the unfavorable impact of high frequencies on the quality of a solution. A damping ratio of 0.5% and an integration time step of Δt=0.01/10 sec, for the 7 time series of two components (x and y) of seismic dynamic loads were applied (for each time series two directions were analyzed, 0° and 180°) and their mean, median and standard deviations results obtained in terms of displacements and accelerations.

The predication of the variability in structural response is important, because it helps to judge margins against undesirable performance. The record selection and scaling was based on a mean target spectrum, such as the uniform hazard spectrum. This means that no defined variability exists in the spectral values. The prediction of the structural response variability is statistically meaningless and will depend entirely on how the records were selected and scaled to match the target spectrum.

The Figure 5 shows the time variations of acceleration and displacement on the tip of the beam (node 3 in Figure 5) of the sign support, for the seismic input corresponding to 001251 time series in the cases without and with TMD.

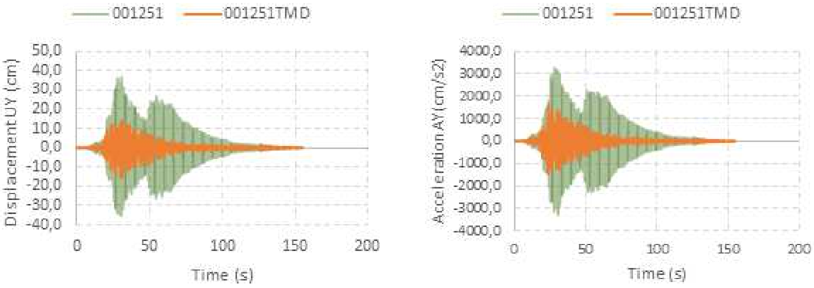

Figure 5: Displacements and Accelerations (Direction y) of Node 3 of the Beam (See Figure 4), without and with TMD Modeled with Mass Ratio of 1% for the Earthquake 001251 Time Series

Table 1 presents a summary of maximum values of displacements and accelerations on node 3 (horizontal direction), for the 7 the time series.

Table 1: Maximum Displacements and Accelerations on Node 3, for each of the Time Series (without TMD) and with TMD (Bold Format)

Earthquake/ Time-Series	Direction	000476	000479	001216	001249	001251	001252	001254	Mean	Median	Standard Deviation
Maximum Displacement (cm)	x	3,1	3,2	2,9	3,2	6,9	4,4	9,5	4,8	3,2	2,5
		3,6	**3,3**	**2,5**	**3,2**	**6,8**	**3,6**	**9,9**	**4,7**	**3,6**	**2,7**
	y	8,1	29,5	13,1	18,1	36,6	14,7	11,1	18,7	14,7	10,4
		9,2	**13,4**	**11,5**	**13,2**	**15,8**	**16,4**	**14,5**	**13,4**	**13,4**	**2,5**
Maximum Acceleration (cm/s^2)	x	874,2	997,1	325,5	743,7	914,5	2636,3	1337,4	1118,4	914,5	734,5
		917,1	**1018,7**	**343,5**	**714,9**	**965,7**	**2521,8**	**1348,2**	**1118,6**	**965,7**	**690,3**
	y	1332,2	2684,6	1223,3	1642,1	3282,4	2457,0	1742,5	2052,0	1742,5	768,9
		1595,9	**1263,5**	**1189,2**	**1270,9**	**1625,1**	**2021,7**	**1506,6**	**1496,1**	**1506,6**	**289,3**

All the subsequent considerations are towards to the y direction, due to the TMD was tuned for the fundamental model vibration. In general, in the x direction, the TMD has produce no overall structural benefits. For the y direction, the maximum displacement and acceleration was found for the 001251 time-series, where in addition the TMD proved to be the most effective. The 000476 time-series displayed the minimum displacement and acceleration of all the 7 cases, in this particular situation the TMD has amplified slightly the response.

The efficiency on the use of the modeled TMD on the structure can be interpreted by the results of Table 1, here associated with mass ratio of 1%: reduction of maximum displacements and accelerations (mean values) in the y direction on the order of 28% and 14%, respectively.

Another parameter that deserves attention is the standard deviation, for the case with TMD installed, there is a substantial reduction of the structural response variability (displacements and accelerations).

CONCLUSIONS

The paper introduces and describes a procedure for selecting and scaling natural records of earthquakes for the study of cantilevered sign support structures. The herein suggestions follows the EC8-1 (Portuguese National Annex) prescription for a particular sign support located in the south of Portugal (Faro).

Regarding the implementation of the TMD, it was concluded that this device is proving to be effective in terms of displacements and accelerations reductions when the structure is subjected to the scaled natural records, but only in the y direction (fundamental vibration mode). For the TMD modeled with the parameters calculated, it was concluded that in terms of maximum accelerations (mean values) reductions of the order of 28% can be achieved for a TMD with 1% mass ratio. For the maximum displacements (mean values) it was concluded that the structural reference system has proved less effective, achieving reductions of 14% for a TMD with 1% mass ratio. In the present paper, the implementation of the TMD was only considered the out-plane direction (y direction associated with the fundamental vibration mode), future studies should focus ways to provide effective damping in both directions, as a combination of two damping devices. From a structural system perspective, the in-plane and out-of-plane behaviors are almost uncoupled (modes of vibration); hence the movement (and suppression) can be considered independently and superimposed.

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REFERENCES

1. Ambraseys N, Smit, P, Berardi R, Rinaldis D, Cotton F, Berge C (2000): Dissemination of European strong-motion data (Cd-Rom Collection). European Commission, Dgxii, Science, Research and Development, Bruxelles.
2. Ambraseys NN, Douglas J, Rinaldis D, Berge-Thierry C, Suhadolc P, Costa G, Sigbjornsson R, Smit P (2004): Dissemination of European strong-motion data, Vol. 2, Cd-Rom Collection, Engineering and Physical Sciences Research Council, United Kingdom.
3. Bazzurro P, Cornell CA (1999): Disaggregation of seismic hazard, Bull. Seismol. Soc. Am., 89, 501–520.
4. Beyer K, Bommer JM, (2007): Selection and scaling of real accelerograms for bi-directional loading: A review of current practice and Code Provisions. Journal of Earthquake Engineering, 11:13-45, DOI: 10.1080/13632460701280013
5. Bommer JJ, Acevedo AB (2004): The use of real earthquake accelerograms as input to dynamic analysis. Journal of Earthquake Engineering, Vol. 8:43-91, 2004. Special Issue, 1.

6. CEN (2004a). Eurocode 8: Design of structures for earthquake resistance- Part 1: General Rules, seismic actions and rules for buildings, Brussels, Belgium.
7. CEN (2004b). Eurocode 8: Design of structures for earthquake resistance- Part 5: Foundations, retaining structures and geotechnical aspects, Brussels, Belgium.
8. Cornell C.A. (1968): Engineering Seismic Risk Analysis, Bull. Seismol. Soc. Am., 58, 1583-1606.
9. Fonseca JFBD, Vilanova SP (2012): Overview on current seismic hazard disaggregation studies for Western Iberia and Consequences for ground shaking scenarios for Lisbon, 15th World Conference on Earthquake Engineering, Lisbon, Portugal.
10. Iervolino I, Maddaloni G, Cosenza E. (2008): Eurocode 8 compliant real record sets for seismic analysis of structures, Journal of Earthquake Engineering, 12(1): 54–90.
11. Iervolino I, Cosenza E, Galasso C (2009): Shedding some light on seismic input selection in Eurocode 8, E. Conseza (ed.), Eurocode 8 Perspectives from the Italian Standpoint Workshop, 3-12, Doppiavoce, Naples, Italy.
12. Iervolino I, Galasso C, Cosenza E (2010). REXEL: computer aided record selection for code-based seismic structural analysis. Bulletin of Earthquake Engineering.8:339-362, DOI 10.1007/s10518-009-9146
13. Katsanos EI, Sextos AG, Manolus GD (2010): Selection of earthquake ground motion records: A state-of-the-art review from a structural engineering perspective. Soil dynamic and Earthquake Engineering 30, 157-167.
14. Montilla, J.A., Casado, CL, Romero, J.H (2002): Disaggregation in magnitude, distance, and azimuth in the South and West of the Iberian Peninsula. Bull. Seismol. Soc. Am., 6, 2177–2185.
15. Paiva F, Barros RC (2013a): Analysis of the stability and design of a cantilever sign support in highways. 4th International Conference on Integrity, Reliability & failure, Funchal, 23-27 June.
16. G. D. Awchat & Yamini. N. Deshmukh, Seismic Response of Tall Building with Underground Storey using Dampers, International Journal of Civil Engineering (IJCE), Volume 6, Issue 4, June-July 2017, pp. 57-66
17. Paiva FM, Barros RC (2013b). Comparisons of a cantilever sign support response subjected to natural wind gusts with and without a TMD. 4th ECCOMAS Thematic Conference on Computation Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2013), Kos Island, Greece, 2013.
18. Sousa M, Costa AC (2009): Ground motion scenarios consistent with probabilistic seismic hazard disaggregation analysis. Application to Mainland Portugal, Bull. Earthquake Eng., 7, 127-147.
19. http://www.seismosoft.com/seismomatch. 23/05/2016.