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COST EFFECTIVE SEISMIC ISOLATION (CESI-SF) SYSTEM FOR EFFICIENT SEISMIC PROTECTION OF BRIDGES

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ABSTRACT

Longer history of European seismicity is well studied. The territory of Kosovo is located in south-east Europe, known as one of the most seismic-prone regions in Europe. Systematic assessing of real seismic resistance of existing bridges in Kosovo region is very important and highly needed strategic activity. Development of advanced and cost-effective method for seismic protection of bridges in Kosovo region is never considered before. Presently initiated innovative research topic and research program actually represent the first and original attempt and pioneering research effort toward development of new technology for efficient seismic protection of bridges. In this paper presented is basic concept of the developed innovative Cost-Effective Seismic Isolation System (CESI-SF System) for bridges, applicable for efficient earthquake protection of multi-span bridge structures under the strongest future earthquakes. Particular emphasis is put on development of seismic isolation and vibration control devices providing high efficiency and cost effective practical application capability.

1. INTRODUCTION

The earthquakes are not rare in Kosovo region and in the case of their occurrence the consequences can be rather destructive. For the region of Kosovo, in the future, the occurrence of much stronger earthquakes have to be regarded as real possibility. Such estimation is realistic, because earthquake surprising phenomenon is confirmed in the past in many regions of the world. Considering the above stated the development of new technology for seismic protection of highway bridges, as the most important infrastructure systems, represent urgent research area and research need.
The high seismic risk pertaining to transportation networks in South East Europe (SEE) is a serious threat to public safety, sustainable economic and social development and security in the region.
This risk has not been quantified to this date and sound seismic risk mitigation concepts are not available. Most of the existing bridges are constructed as non-aseismic and are older than 40 years, so that they are highly vulnerable to seismic loads and require immediate, reliable and cost-effective seismic upgrading.

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The observed severe damages and total collapses of bridge structures in recent earthquakes in many world seismic countries (Japan, Chile, Turkey, U.S.A., China, etc.), Fig. 1.1. and Fig. 1.2., has clearly demonstrated the urgent need for adoption of an advanced technology for qualitative seismic safety improvement of classical existing and new bridge systems.

Figure 1.1. Recently constructed modern bridge type structure (with neoprene pads) in the city of Prishtina

Figure 1.2. Typical modern bridges along highways in Kosovo region

2. MODERN BRIDGE SEISMIC SAFETY ENGINEERING

Structural earthquake engineering that is particularly connected with bridge strategic structures is distinguished and identified as a central and very specific expert activity of the modern world-wide bridge engineering industry.
World experts, in the role of principal design engineers of the most prominent structures worldwide are increasingly organized in very specialized expert teams that put concerted efforts toward realization of specific projects in the field of structural earthquake engineering. Bridges of large proportions are presently increasingly being constructed (Fig. 1.1. and Fig. 1.2.).
As prominent structures and with their appearance, these bridges reflect, in the most transparent way, the evident progress and achievements in modern structural earthquake engineering.

Figure 2.1. Chile earthquake, Magnitude M=8.8, February 27, 2010.

Figure 2.2. Kobe, Japan, M=7.2, 1995, Total Collapse of Hanshin Line.

The development and application of successful systems for seismic protection of distinctively long and large new bridges represents the greatest challenge of the present scientists and experts in the field of structural earthquake engineering.
Due to the uniqueness of the applied structural system and the possible big “surprises” regarding the intensity of seismic effects, it is necessary to carry out specific investigations for the purpose of providing efficient seismic protection of the unique systems of modern bridge structures.

3. INNOVATIVE CESI-SF SYSTEM FOR SEISMIC PROTECTION OF BRIDGES

The proposed CESI-SF System is developed as specific option of GOSEB System, (Ristic et. all, 2012), based on optimized integration of the innovative concepts of Multi-Level (ML) Multi-Directional (MD) Seismic Energy Dissipation and Globally Optimized Seismic Energy Balance (GOSEB). The new CESI-SF seismic isolation and seismic upgrading system for bridges actually represent very important technical innovation capable of integrating the three highly important advantages: Seismic isolation, Seismic energy dissipation and Effective displacement control.
With the achieved advanced seismic isolation and seismic protection performances with created new CESI-SF System, in compliance with the current seismic input energy, complete seismic protection of bridge structures is provided, even under the strongest earthquakes.
In the present paper presented are created four important innovative products of the new CESI-SF System: (1) Prototypes of new SF-Type hysteretic energy dissipation components (EDC), (2) Prototypes of new SF-Type hysteretic energy dissipation devices (EDD), (3) Prototypes of innovative CESI-SF System and (4) Advanced design procedure providing application of CESI-SF System for seismic protection of new and existing bridges. The proposed innovative CESI-SF System actually represents advanced technology, integrating response modification and seismic isolation into advanced system for efficient seismic protection of bridges.

4. TESTS OF SF- PROTOTYPES OF ENERGY DISSIPATION COMPONENTS

The basic experimental laboratory test program included nonlinear quasi-static tests, Table 4.1 of constructed prototype models of the developed new specific space flange types (SF-Type) of seismic energy dissipation components (EDC), used in creation of new energy dissipation devices (EDD).

Table 4.1. Tested prototypes of seismic of energy dissipation components (EDC) of new SF-Type energy dissipation devices (EDD) under simulated earthquake-like reversed cyclic loads

No.	**Tested new energy dissipation components EDC of SF-type**	**Designed EDC prototypes**	**Produced EDC specimens**	**Completed EDC tests**
1	ED Components of Energy dissipation devices (EDD) of space flange SF-class	2	40	5
TOTAL		**2**	**40**	**5**

All EDC prototypes are tested up to strong nonlinearity under cyclic loads (Table 4.1.), since they represent the most basic parts of the developed new type of energy dissipation devices (SF-EDD).

5. TESTS OF SF- PROTOTYPES OF ENERGY DISSIPATION DEVICES

The developed new CESI-SF System can be successfully applied for seismic upgrading of a dominant number of RC bridges with neoprene bearings in Kosovo region and SE Europe in general, Fig. 1.1 and Fig. 1.2.

Figure 5.1. Laboratory tested model prototypes of new seismic energy dissipation devices (EDD) of SF-Class under simulated earthquake-like reversed cyclic loads: Type 1: EDD-SF-T1 and Type 2: EDD-SF-T2

The conducted experimental program included construction and testing of new type of energy dissipation device (EDD), Table 5.1, under simulated reversed cyclic loads.
The basic structure of ML-MD Energy Dissipation Devices of space frame SF-Class is shown in Fig. 5.1. In the following Fig. 5.2, presented are original hysteretic relations defined experimentally for the tested two specific innovative types of energy dissipation devices (EDD) of SF-Class.

Table 5.1. Prototypes of constructed and tested new energy dissipation devices (EDD) of SF-class under simulated earthquake-like reversed cyclic loads

No.	Prototypes of innovative energy dissipation devices (EDD)	Number of designed EDD	Number of produced EDD	Completed exp. tests
4	ML-MD Energy dissipation devices (EDD) of space flange SF-class	2	2	2
TOTAL		**2**	**2**	**2**

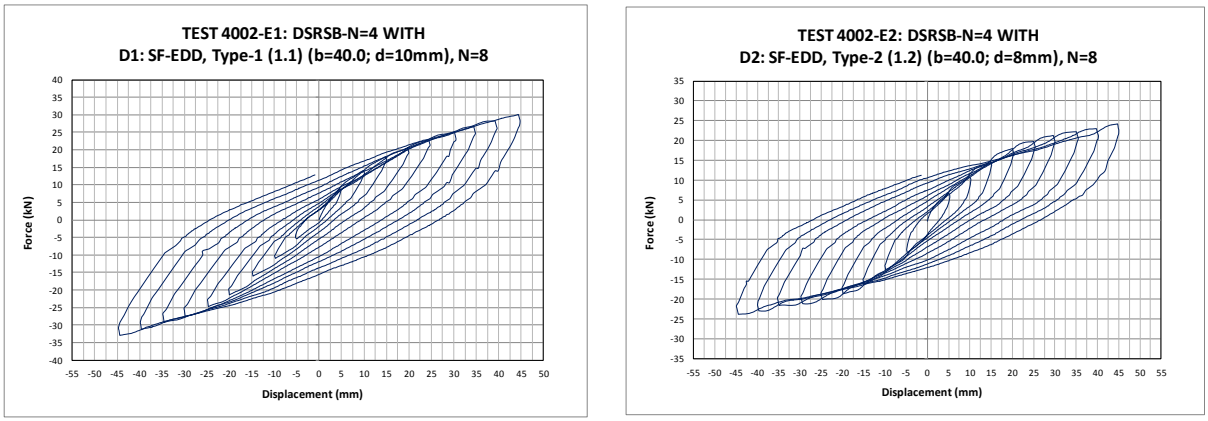

Figure 5.2. Experimentally defined original hysteretic relation of the developed two specific innovative types of energy dissipation devices (EDD) of space flange SF-Class

6. SHAKING TABLE TESTS OF BRIDGE MODEL WITH NEW CESI-SF SYSTEM

The actual experimental program included creation, construction and testing of representative prototype of bridge shaking table model composed of innovative type of seismic protection system (Figure 6.1).

BM4:
Vibration Periods
T_1=0.255 s (y)
T_2=0.254 s (x)
T_3=0.122 s (xy)

WEIGHT OF MODEL SLAB:
Q_0=83.25 kN

ADDED LOAD:
q=1.5 kN/m^2
Q_a=16.65 kN

SUPER–STRUCT. WEIGHT:
Q_S= 99.9 kN

Figure 6.1. Large-scale bridge test model with innovative CESI-SF-BM5-RB seismic isolation systems and typical columns with different pier's stiffness.

In this paper presented is one representative bridge test model (BM4), with integrated innovative so called CESI-SF System. For this innovative option of large-scale shaking table bridge test model

(BM4), initially were completed representative experimental quasi-static tests and after that, dynamic shaking table test under simulated shaking effects of the selected real recorded strong earthquake ground motions. The completed experimental seismic shaking table tests serve as realistic experimental validation of the actual response modification performances and efficiency of the created innovative CESI-SF bridge seismic isolation system for seismic upgrading of existing and seismic protection of new bridges.
The innovative bridge model 4 (BM4) exists of CESI-SF energy dissipation devices and basic seismic isolation system composed of DSRSB bearings and is denoted as CESI-SF-BM4-DSRSB. Test set-up and all quasi-static and dynamic tests are realized based on defined optimal test program for bridge model-4.

Figure 6.2. Constructed innovative large-scale bridge model tested on seismic shaking table with incorporated new CESI-SF seismic protection system (BM4).

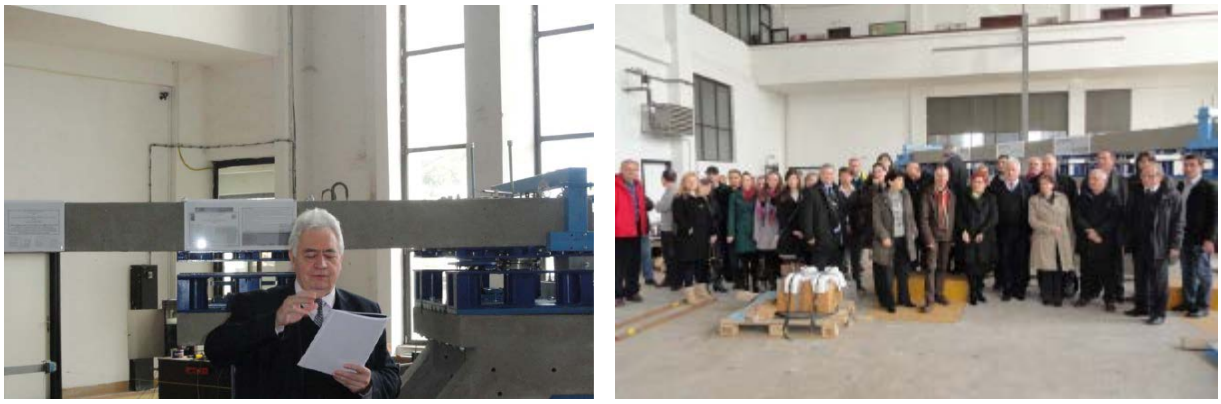

Figure 6.3. Moments from laboratory tests demonstration day: Demonstration of the advantages of the developed new seismic isolation systems for seismic protection of bridges.

In Figure 6.2, presented is constructed innovative large-scale bridge model tested on seismic shaking table with incorporated new CESI-SF seismic protection system (BM4), while Figure 6.3 shows moments from laboratory test demonstration day: Demonstration of the advantages of the developed CESI-SF seismic isolation system for seismic protection of bridges.

7. MODELING OF TESTED BRIDGE MODEL WITH NEW CESI-SF SYSTEM

To obtain basic system verification and evaluation results, very extensive analytical seismic response studies have been performed considering the designed innovative laboratory bridge test model prototype with incorporated an optimized CESI-SF seismic isolation system.
The integral analytical study of seismic response characteristics of the designed bridge model with CESI-SF system are carried out using experimental Bridge Model-4 comprizing of middle columns with different stiffness. The constructed large scale experimental bridge model structure-4 exists with

three bridge spans and its total length is L=7.40+2x0.20+2x0.25=8.30m (Fig. 6.2).
The superstructure is designed as a stiff continuous system composed of RC tick slab d=30cm, width b=150cm and length l=740cm.

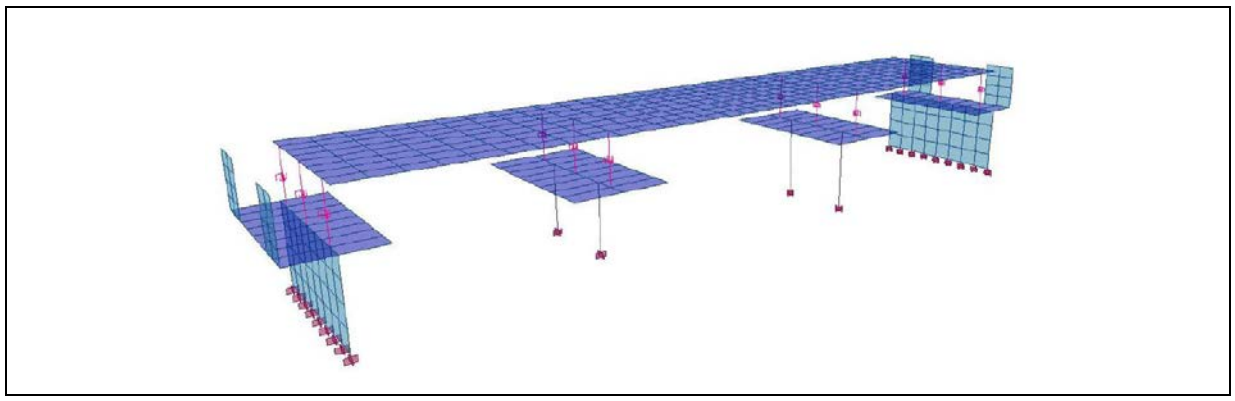

Figure 7.1. Formulated 3D mathematical model of large-scale bridge test model-4 constructed with innovative CESI-SF seismic protection system

The sub-structure consists of two specially designed RC end supports (abutments) and two steel middle piers with different heights (Formed of pairs of two steel piers with D=160mm). Hight of left and right pier are h1=60cm and h2=80cm, respectively. The piers are fixed to the stiff RC footings and on the top are connected with appropriately designed RC cap beam.
The RC superstructure slab is supported by eight (8) DSRSB seismic isolators installed at both sides on the top of four specially designed steel supports (installed above the two abutments and two middle piers). At all four bridge supports, new innovative seismic energy absorbers of type CESI-SF, are considered. They are active in longitudinal direction, transverse direction, or in general case active are in all directions and respectively are named as multi directional (MD).

8. SEISMIC RESPONSE CHARACTERISTICS OF NEW CESI-SF SYSTEM

Formulated 3D mathematical model of the constructed large-scale Experimental Bridge Model-4 with integrated innovative CESI-SF seismic isolation systems is presented in Figure 7.1. Extensive seismic response study was performed applying the formulated nonlinear mathematical model, considering as input the effects of very strong earthquake ground motions. RC superstructure slab and RC substructure elements are modeled with shell finite elements. The existing steel middle piers are modeled with 3D beam finite elements, while DSRSB ismic isolators, as well as energy dissipating devices are modeled with nonlinear link elements.

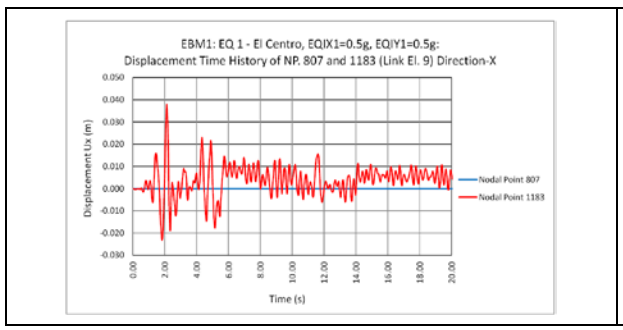

Figure 8.1. Displacement response DX(m) of NP=807 & NP=1183 (LS). EQ: El-Centro, EQI-0.7g.

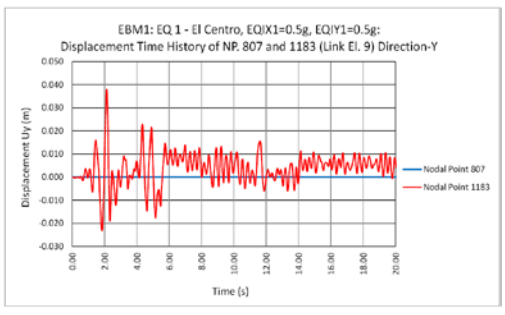

Figure 8.2. Displacement response DY(m) of NP=807 & NP=1183 (LS). EQ: El-Centro, EQI-0.7g.

For this considered option-4 of bridge structural system, non-linear seismic response of the modeled structure was analyzed using two different earthquake records: (1) El-Centro record and (2) Ulcinj-Albatros record.
The PGA of both records were scaled to extremely high intensity level (PGA=0.7g), acting inclined

for 45 degrees in respect to the bridge longitudinal axis.

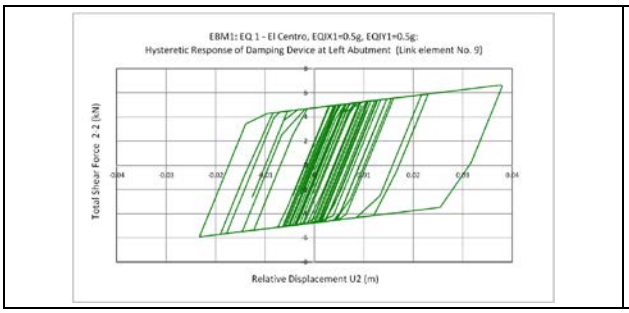

Figure 8.3. Hysteretic response of CESI-SF at left end-support. DIR-X. EQ: El-Centro, EQI-0.7g.

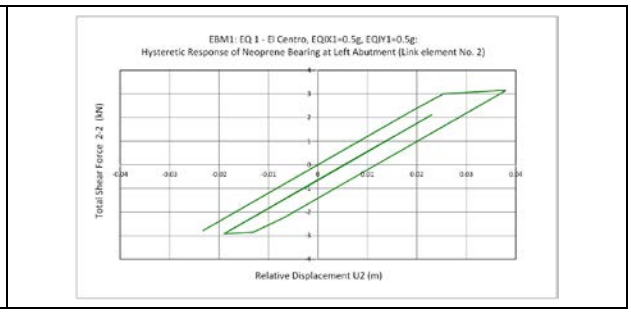

Figure 8.4. Hysteretic response of RB-1 at left end-support. DIR-X. EQ: El-Centro, EQI-0.7g.

So, in such specific case, the bridge is excited simultaneously in longitudinal direction and in transverse direction with identical seismic input components, having very high PGA=0.5g. Here are presented only selected typical response results for left bridge support, demonstrating the actual seismic performances of CESI-SF seismic isolation system.
From the observed integral results and presented results, evident is very favorable behavior of the analyzed bridge system-4, denoted as CESI-SF seismic protection system.

9. CONCLUSIONS

Considering research results obtained from the conducted extensive experimental and theoretical study presented above, using designed innovative bridge model prototype structure-4, the following general conclusions are derived: (1) The optimized seismic isolators are very effective for bridge seismic vibration control. However, for any particular bridge, seismic isolators should be designed based on advanced optimization process; (2) The new multi-level multi-directional CESI-SF hysteretic seismic energy absorbers possess unique energy absorption features since they are capable of adapting their behaviour to the actual intensity of seismic input energy. Actually, the new CESI-SF hysteretic energy absorbers provide the most innovative and advanced features of multi-level earthquake response in all directions; (3) The optimized displacement bound devices are very effective for excessive displacement control of the bridge superstructure. It is clear that the CESI-SF displacement stoppers represent highly efficient system devices providing additional contribution to the improvement of the bridge seismic safety, particularly in the case of very strong earthquakes; (4) The new CESI-SF high performance seismic isolation system for bridges, created based on an optimized seismic energy balance actually is very effective technical innovation capable of integrating the advantages of seismic isolation, seismic energy dissipation and effective displacement control; (5) The new CESI-SF seismic isolation system for bridges based on multi-level seismic energy absorption and optimized seismic energy balance shows very high seismic control performances and can be used for full seismic protection of bridges in longitudinal and transversal direction under the effect of very strong earthquakes; and (6) In the next study fhases specific research activities should be devoted to analytical paramertic evaluation of seismic performances of the new CESI-SF system implemented in real characteristic prototype bridge systems which arec designed with different geometrical properties and subjected to different earthquake intensities and frequency content.

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