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EFFICIENT SEISMIC PROTECTION OF BUILDINGS WITH NEW GOSEB-ZK SEISMIC ISOLATION SYSTEM

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ABSTRACT

Improvement of seismic protection of building structures in Kosovo region is very important task and strategic research activity. Development of advanced seismic isolation method for seismic protection of buildings in Kosovo region is never considered before. The present research actually represent the first attempt and pioneering research effort toward development of new technology for efficient seismic protection of different types of important building structures in the well known seismically prone Kosovo region. In this paper presented is basic concept of the developed new GOSEB-ZK seismic isolation system for seismic protection of existing and new multi storey buildings. The proposed system is applicable for economical earthquake protection of building structures of different usability categories and different types under destructive effects of the strongest future earthquakes. Particular emphasis is put on development of seismic isolation and vibration control devices providing high practical efficiency and effective application capability.

1. INTRODUCTION

It seems that earthquake catastrophes have lately become increasingly devastating. The world is simply shocked while watching the TV broadcasts on different regions in the world stricken by earthquakes. Ordinary people wonder and cannot accept to believe that such severe consequences from each new earthquake are still possible today, at the present level of technological development.

In our minds, there are strong memories of the stirring pictures of the latest earthquakes that have occurred around the world. The most recent event was the earthquake in Turkey with over 18 000 victims, many more injured and thousands of heavily damaged and collapsed buildings. Similar devastating effects have been also observed in the latest earthquakes that struck many other countries like Greece, Taiwan, Japan, China, United States, Russia, Italy, Montenegro, Algeria, Mexico, Peru, etc. The losses caused by the earthquake that took place in the city of Kobe, Japan in 1995, is estimated at more than 200 billion dollars and all this happened within only 20 – 30 seconds. More than 5500 people lost their lives and even more were injured.

The prevention of such heavy earthquake catastrophes in the future was the main and challenging motivation of the first author, to start with the realization of the original innovation (pilot) project

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entitled “Seismically Safe Cities of the Future”. This project actually represents the author’s “creative vision for construction of seismically safe structures in the twenty-first century”, without increase of total construction cost. To provide the necessary basic technical conditions for practical realization of his visionary idea about an efficient seismic protection of structures in future, promoted is application of a new and qualitatively improved technology.

The advanced technology for a qualitatively improved seismic protection of buildings in future is based on application of new “GOSEB-ZK” seismic isolation system efficient for construction of seismically safe structures. The “GOSEB-ZK” seismically resistant system is based on the concept of global optimization of seismic energy balance. This has been achieved by integration of the advantages of seismic isolation systems and the new concept for multi-level seismic energy absorption, realized with new “GOSEB-ZK” System (Fig. 1.1. and Fig. 1.2.).

Figure 1.1. Concept of The New “GOSEB-ZK” Seismo-Resistant System Based On Multi-Level Seismic Energy Absorption and Global Optimization of Seismic Energy Balance

Seismic isolator is available on the market and it is produced in different proportions and with diverse physical characteristics. This enables wide and universal application of seismic isolators in all kinds of structures.

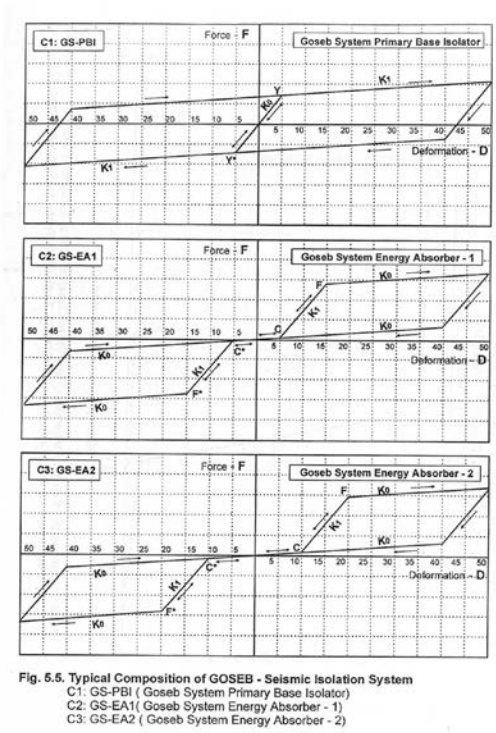

Figure 1.2. Concept of the Invented Multi-Level Seismic Energy Absorber

The new multi-level "GOSEB-ZK" hysteretic seismic energy absorber has extraordinary features as to adapting its behavior to the actual level of seismic input energy. Actually, "GOSEB-ZK" hysteretic energy absorber possesses the following features of multi-level earthquake response:
1. If there is no earthquake excitation, the "GOSEB-ZK" hysteretic seismic energy absorber enables behavior of the structure analogous to the behavior of any traditionally constructed structure.
2. If a relatively slight earthquake occurs, the "GOSEB-ZK" hysteretic seismic energy absorber reacts with an adequate level of dissipation of the input seismic energy, making the structure thoroughly safe and avoiding even micro-cracks.
3. If a moderate earthquake occurs, the "GOSEB-ZK" hysteretic seismic energy absorber reacts with an adequately increased level of dissipation of the input seismic energy. This enables complete protection of the structure.
4. Finally, in the case of the most severe earthquake, the "GOSEB-ZK" hysteretic energy absorber reacts with its full capacity for dissipation of the increased seismic input energy level.
The required full capacity for seismic energy dissipation has been defined by advanced design analyses, in the theoretical part of the investigations of the optimal seismic performances of the "GOSEB-ZK" multi-level seismic energy absorber.
The multi-level response of the "GOSEB-ZK" system in compliance with the input seismic energy provides a complete seismic protection of structures, even under the strongest recorded earthquakes.
In the present paper presented are created four important innovative products of the new GOSEB-ZK System: (1) Prototypes of new hysteretic energy dissipation components (EDC V-Type), (2) Prototypes of new hysteretic energy dissipation devices (EDD V-Type), (3) Prototypes of innovative GOSEB-ZK System and (4) Advanced design procedure providing application of new GOSEB-ZK System for seismic protection of new and existing buildings. The proposed innovative GOSEB-ZK System actually represents new advanced technology, integrating response modification and seismic isolation into new system for efficient seismic protection of all types of buildings.

2. TESTING OF NEW V-CLASS ENERGY DISSIPATION COMPONENTS

The basic experimental laboratory test program included nonlinear quasi-static tests, Table 2.1., of constructed prototype models of the developed new specific vertical class (V-Type) of seismic energy dissipation components (EDC), used in creation of new energy dissipation devices (EDD).

Table 2.1. Tested prototypes of seismic of energy dissipation components (EDC) of new V-Class energy dissipation devices (EDD) under simulated earthquake-like reversed cyclic loads

No.	**Tested types of energy dissipation components EDC of created new energy dissipation device EDD**	**Designed EDC prototypes**	**Produced EDC specimens**	**Completed EDC tests**
1	ED Components of Energy dissipation devices (EDD) of vertical V-class	12	92	13
TOTAL		**12**	**92**	**13**

All EDC prototypes are tested up to strong nonlinearity under cyclic loads (Table 2.1.), since they represent the most basic parts of the developed new type of energy dissipation device (EDD).

3. TESTING OF NEW V-CLASS ENERGY DISSIPATION DEVICES

The developed new GOSEB-ZK System can be successfully applied for seismic protection of new buildings and seismic upgrading of a dominant number of important existing buildings with classical system constructed in Kosovo region and SE Europe in general. The presently conducted extensive experimental program included also the construction and testing of new type of energy dissipation device (EDD), Table 3.1, under simulated reversed cyclic loads.

Table 3.1. Prototypes of constructed and tested new energy dissipation devices (EDD) of vertical V-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
1	ML-MD Energy dissipation devices (EDD) of vertical V-class	2	2	2
TOTAL		**2**	**2**	**2**

Figure 3.1. Laboratory tested model prototypes of new seismic energy dissipation devices (EDD) of vertical V-Class under simulated earthquake-like reversed cyclic loads: Type 1: EDD-V-T1 and Type 2: EDD-V-T2

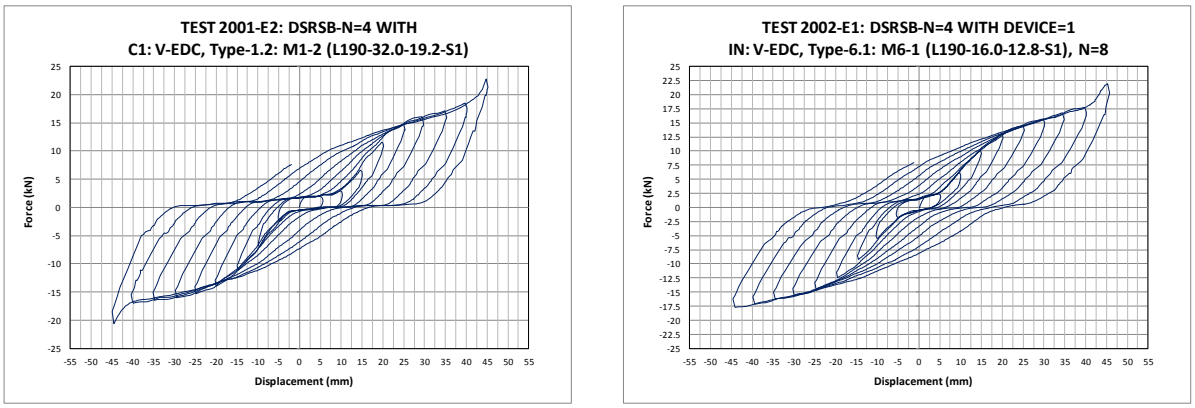

Figure 3.2. Experimentally defined original hysteretic relations of the developed two specific innovative types of energy dissipation devices (EDD) of vertical V-Class

The basic structure of new ML-MD Energy Dissipation Devices of vertical V-Class is shown in Fig. 3.1. In the following Fig. 3.2, presented are original hysteretic relations defined experimentally for the tested two specific innovative types of energy dissipation devices (EDD) of V-Class.

4. TEST MODEL OF PROTOTYPE BUILDING WITH NEW GOSEB-ZK SYSTEM

The actual experimental program included creation, construction and testing of representative prototype of building shaking table model composed of innovative type of seismic protection system.

In this paper presented is one representative building test model with integrated innovative so called GOSEB-ZK System. To define set-up parameters for this innovative large-scale shaking table building model and to conduct final dynamic shaking table test under simulated effects of the selected real and strong earthquake ground motions, specific and representative experimental quasi-static tests have been firstly completed. The results obtained from the completed experimental seismic shaking table tests represent highly valuable basis for realistic experimental validation of the actual response modification performances and efficiency of the created innovative GOSEB-ZK seismic isolation system for seismic upgrading of existing and seismic protection of new buildings.

Figure 4.1. View of constructed large-scale building model tested on seismic shaking table (a) and detail of seismic isolation and energy dissipation devices (b) of the proposed seismic protection system for buildings

The innovative building model 2 exists of GOSEB-ZK energy dissipation devices and basic seismic isolation system composed of double sferical ruler seismic bearings (DSRSB) and is denoted as GOSEB-ZK-DSRSB. Test set-up and all quasi-static and dynamic tests are realized based on defined optimal test program for building model-2. In Figure 4.1 presented is constructed innovative large-scale building model tested on seismic shaking table with incorporated new GOSEB-ZK seismic protection system. In IZIIS dynamic testing laboratory was organized valuable public workshop representing laboratory test demonstration day. With conducted representative shaking table model tests, demonstrated was to the audience real advantage of the developed new GOSEB-ZK seismic isolation system for seismic protection of buildings.

5. SEISMIC TESTING OF BUILNING MODEL WITH NEW GOSEB-ZK SYSTEM

To generate basic results for new system verification, extensive experimental seismic tests been performed using the constructed innovative laboratory building test model prototype with incorporated an optimized GOSEB-ZK seismic isolation system.

The building model was constructed in the scale 1:3, so planed seismic tests have been carried out using time compressed real earthquake recorts by factor $1/\sqrt{3}$. The building model was constructed as two storey building frame structure with brick masonry infill and represent isolated segment of selected typical real building from Kosovo and wider region of south-east Europe.

The dimensions of the model in plan are a=3.14m and b=1.74m., while hights of the stories are h=1.08m. The model superstructure was supported by four (4) DSRSB seismic isolators installed on the top of four specially designed steel supports installed at four model corners for simulation of supporting system above fundations.

At both model ends between supports, new innovative seismic energy absorbers of the type GOSEB-ZK are installed. During seismic tests, seismis isolation system is activated directly in longitudinal direction by simulated earthquake input motion.

The tested building model with integrated innovative GOSEB-ZK seismic isolation systems is presented in Figure 4.1. Extensive seismic tests have been performed considering as input the effects of very strong earthquake ground motions. The superstructure of the tested building model did not received any damage during all seismic tests. Intersory drifts have been reduced to a minimum and

only significant displacements have been recorded at the level of building supporting system. Seismic tests of the building model have been performed using several different very strovg earthquake records. However, in this paper are included only selected experimental results to demonstrate the main contribution of the conducted tests for realistic evaluation of the achied very favourable seismic performances if the developed system.

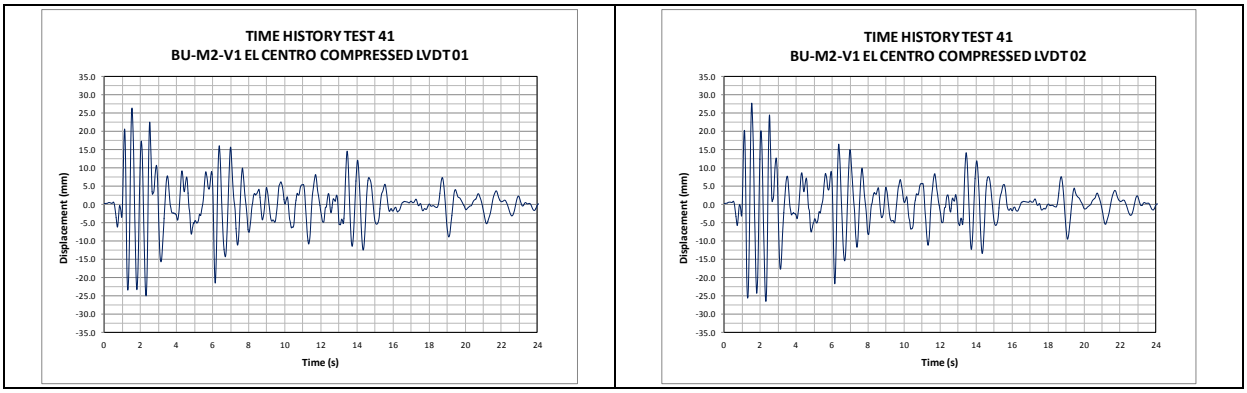

Figure 5.1. Experimentally defined original displacement response history of points NP=1 and NP=2 of building model with the developed innovative type of building seismic protection system GOSEB-ZK with energy dissipation devices (EDD) of vertical V-Class

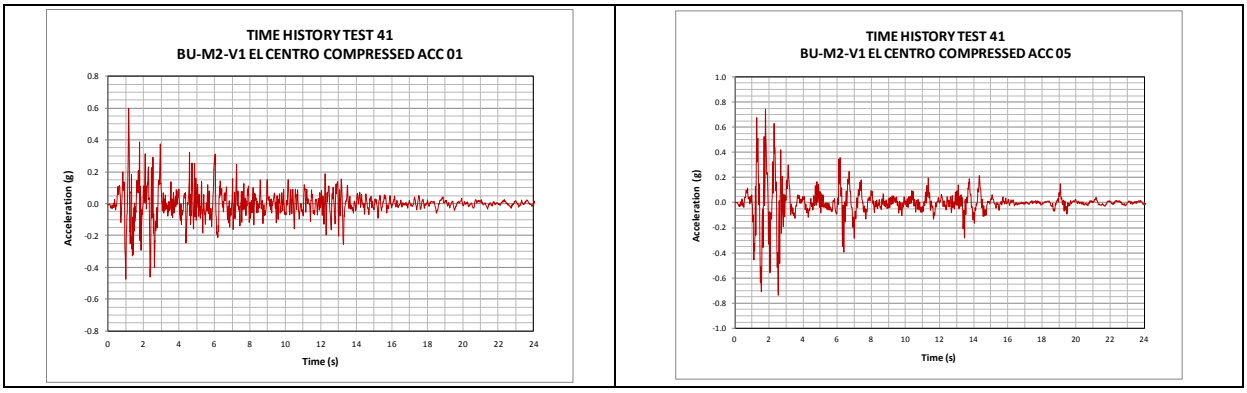

Figure 5.2. Experimentally defined original acceleration response history of points NP=1 and NP=2 of building model with the developed innovative type of building seismic protection system GOSEB-ZK with energy dissipation devices (EDD) of vertical V-Class

In Figure 5.1, presented are experimentally defined original displacement response history of points NP=1 and NP=2 of building model with the developed innovative type of building seismic protection system GOSEB-ZK with energy dissipation devices (EDD) of vertical V-Class. In the next Figure 5.2, presented are experimentally defined original acceleration response history of points NP=1 and NP=2 of the model with the developed innovative type of building seismic protection system.
From the observed integral experimental results, evident is very favorable behavior of the developed building system denoted as GOSEB-ZK seismic protection system.

6. CONCLUSIONS

The most important conclusion from this extensive study is experimental confirmation that the proposed new seismo-resistant GOSEB-ZK system can be used as efficient system for complete seismic protection of buildings based on innovative multi-level seismic reaction and globally-optimized seismic energy balance. This is achieved by simultaneous application of the advantages of seismic isolation systems and newly developed “GOSEB-ZK” multi-level hysteretic seismic energy absorber. The “GOSEB-ZK” multi-level seismic energy absorber has extraordinary features as to

adapting its behavior to the actual intensity of the input seismic energy. It means that newly proposed "GOSEB-ZK" multi-level seismic energy absorber shows advanced features of multi-level earthquake response.

The full capacity and advances of seismic energy dissipation device has been defined by advanced design analyses in the theoretical part of the investigations. The optimal seismic performances of the new "GOSEB-ZK" ML-MD seismic energy absorber have been defined.

The multi-level response of the "GOSEB-ZK" system in compliance with the input seismic energy provides a complete seismic protection of the structure even under the strongest recorded earthquakes.

The most important advantage of the new seismically resistant "GOSEB-ZK" system for seismic protection of building structures actually is provided condition for its simple application localized only at the base of the structure for which the "GOSEB-ZK" seismic protection is designed.

The skill of the design engineer is reflected through the determination of an optimal number, optimal physical characteristics and optimal position of the seismic isolators and multi-level seismic energy dissipaters to achieve the optimized seismic energy balance for each specific structure.

The present research practically will open a wide field of practical application of the patented globally optimized system of seismic energy balance and realization of the creative vision for construction of seismically resistant structures in the 21st century, as well as further realization of the innovative project "Seismically Safe Cities of the Future".

AWARDS RECEIVED

The originality and high potential of this specific innovative project are very well recognized up to date. This is directly confirmed by received the highest awards in the area of inventions:

• First, the invention was awarded with gold medal in the field of civil engineering at the 23-rd International exhibition of inventions held in Geneva, Switzerland from 31.03. to 09.04 1995.

• Second, in 1996 the invention was awarded with distinguished unique national award "Patent of the Year" in the Republic of Macedonia.

• Third, in February 1998 the innovation was awarded with "Gold medal with mark" at the International exhibition of inventions held in Casablanca, Morocco.

• Forth, on September 1999 the innovation was awarded with the highest national award "Patent of the Decade" by the Government of the Republic of Macedonia.

• Finally, this project was promoted at EXPO-2000, the millennium world exhibition of inventions and new technologies for the 21st century, held in Hanover, Germany, (June 1 to October 31, 2000). The project was officially nominated by the Government of the Republic of Macedonia to represent new and advanced national achievements in the field of INVENTIONS AND SCIENCE. At present related theoretical and experimental research activities are continued by the first author, research team and active MSc and PhD students.

ACKNOWLEDGEMENT

To successfully realize the creative and complex research activities in the area of development of this specific innovation (by the first author), great and highly appreciated support to was extended by many individuals and institutions, both domestic and from abroad. Particularly, the first author is pleased to mention the Industrial Property Protection Office-Skopje, Ministry of Economy and Macedonian Ministry of Education and Science, for initial financing his innovative three year scientific project involving basic development of the innovative GOSEB-System.

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