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MY INVENTIONS

(instead of an introduction)

The aim of this illustrated monograph is to represent a part of significant research, designs and implementations of new construction systems and DC90 equipment for increasing the safety of buildings. It is especially important to represent pieces of research conducted from 2001 until 2013 for the needs of System DC90 development.
Author’s special wish is that the most influential contributors to the development of the inventions, testing, design, implementation and scientific developments give their impressions of this integral process. I will list them in alphabetical order: Prof. Gocevski Vladimir, PhD, Prof. Krstevska Lydia, PhD, Prof. Šumarac Dragoslav, PhD and Prof. Taškov Ljubomir, PhD.

Increasing the safety of structures under dynamic conditions can be achieved through new forms of structural systems and special devices which can control their behaviour. The development of new materials for those purposes is a particular field of activity and was not treated in this monograph. Dominant structures, discussed here, are: masonry, reinforced concrete and steel structures.

Basic physical quantities which define the state of the structures exposed different influences are: length (L), mass (m) and time (t). Knowing the properties of the material under influence defines the state of structures unambiguously at all stages of the influence duration. Generally speaking, the state of a material point in relation to its previous state is defined by twelve parameters. Six parameters define the movement of the material point as a totality, three displacements (x, y, z) and three rotations (φ_x, φ_y, φ_z); six deformation values define the changes in shape, i.e., three dilatations (ε_{xx}, ε_{yy}, ε_{zz}) and three sliding Slip values (γ_{xy}, γ_{yz}, γ_{xz}) in coordinate axis of the Cartesian system (x, y, z). In addition, it is necessary to know the deformation values dependence on the stress, i.e., it is necessary to know the rheological properties of the material defined by the nature of the material and the type of the load. It is of particular importance to understand the relationship function between the strain vector (ε_{xx}, ε_{yy}, ε_{zz}, γ_{xy}, γ_{yz}, γ_{xz}) and the stress vector (σ_{xx}, σ_{yy}, σ_{zz}, τ_{xy}, τ_{yz}, τ_{xz}) during the structure life span. Owing to the tensor symmetry (3x3 = 9 components) deformation and stress are represented as vectors (6 components).

Due to **imperfections and inhomogeneity** of the construction materials structural elements act differently when exposed to loads, pressure and tension. Global and local buckling phenomena have also been observed. Shapes or forms of buckling have been noted, as well, and the most important one is the basic form or the first step of buckling извијања. Very few of actual constructions are likely to lose their stability in second or third form. It is of particular importance to identify **the basic steps or forms of** structures **oscillations.**

Ideally elastic materials do not exist. Actual building structures perform in a nonlinear way with the participation of damping in the element connections and the damping in the atomic structure of the construction materials. Special nonlinear behaviour of the constructions is defined by a form of hysteresis damping after crossing the elastic limit behaviour.

Rheological characteristics of the material are complex and in a large extent determinate the behaviour of the structures whether the period of the influence is short or long compared to the structure life span. I will mention only a few of them: fatigue in the field of large dilatations ε, (5%, 10% or more %) and fatigue in the field of small dilatations ε (of only a few permills), and their influence on the mechanical properties; the change of Coulomb friction coefficient depending on the number of friction cycles and the size of displacement, shrinkage, flowing, relaxation, the effect of temperature, humidity and aging time.

Modern fast computer technology using design discretization methods (DDM) and the method of iteration (step by step with small increments), allows us to solve problems of structural engineering very efficiently and with mathematically ideal accuracy, which was unimaginable until recently, and with an acceptable cost for such analysis.
Knowing the strain-stress dependence behaviour at all stages of the elastic and plastic work and knowing fracture mechanics, i.e., formation and propagation of cracks and using finite element homogenization techniques after the appearance of the first crack, as well as the changes in the Coulomb friction coefficient in such a homogenized element, modern numerical analysis gives quite satisfactory results.
Of course, comparison with the experimental results on all levels (micro, meso, macro and global level of the structure as a whole) is necessary.

In my opinion, without long-term, systematically based on scientific grounds and observed behaviour models of structures in laboratory tests, and tests on actual objects, it is not possible to understand this phenomenon and the structures' behaviour. Experimental programmed research of materials' behaviour under different conditions and under different influences in combination with sophisticated numerical analysis can give almost complete answers to the structural engineering problems. All of this makes the complexity of designing new structural systems or devices which enhance the safety and provide quality and cost-effectiveness.

The main emphasis in the monograph I put on the problems of my inventions which I know the best.
Why the invention? What is an invention?
The need to constantly think about solving a technical problem in an original manner, previously unknown, led to the creation of inventions and their protection through recognized patent solutions. Luckily, I was able to realize such a kind of creativity and to sustain it over a longer period of time to the present day, with a perspective of continuing. The first patent was registered in December of 1989 at the Serbian Institute for Materials' Research. Through fifteen granted patents I included:

- structural systems in buildings with increased safety,
- hysteretic devices for damping earthquake strikes,
- hysteretic damping devices for long-term vibration (wind, machine, human invasion etc.)
- sliding support with movement limiters,
- prefabrication technology of reinforced concrete elements in flexible manufacturing systems
- flexible moulds,
- formwork systems of reinforced concrete structures ,
- masonry systems for energy efficient buildings in seismic conditions and
- Architectural Heritage Protection Systems - old masonry structures.

This monograph systematizes only one part of this research. Gratitude for the support and participation in the creative process I owe primarily to the above mentioned contributors, many other associates, daughters Dragana Obrenovic, economy international ???? marketing, and Jasminka Petrašković-Dzuklevski, B.Sc. Civ Eng, and to my brother Zarko Petrašković, B.Sc. Civ Eng. as longtime associates.

Zoran Petrašković, PhD.
Author of System DC90

COMMENTS ON THE MONOGRAPH:

System DC90 - Structural protection systems
RESARCH-DESIGN-APPLICATION

My contact with the DC-90 system and PhD Zoran Petrashkovic, the author of this Monograph, was established in 2003, during his presentation of DC-90 system at IZIIS. Back then, very few applications of dampers on masonry structures had been made in the earthquake engineering design practice. Some of the seismic experts were very conservative in their opinion about the effectiveness of this system for seismic strengthening of the brick-masonry structures.

From my point of view, the DC-90 system is a very smart solution for seismic protection not only for masonry structures but also for the RC frame structures. Two aspects are basic for the system:

- Control of lateral deformations and stability of the structures
- Dissipation of the seismic energy by plastic deformation of the damper under low-cycling fatigue.

It is easy to design the dampers with large deformation capacity such as hydraulic-viscous dampers, which are applicable for RC or steel frame structures. But design of the dampers for masonry structures, where the lateral deformations are very small and hysteretic damping is very large, is a very difficult task. The DC-90 dampers are unique in that respect: large damping capacity for small inter-storey drift of the buildings amounting to only a few millimetres.

In the past ten years of our cooperation, my duty was to contribute in experimental efficiency testing of the dampers in laboratory and in field conditions. We spent lot of time in discussions and dealing with details. We started testing the buildings by ambient and forced vibration method before and after strengthening by DC-90 system since the year 2004, in order to define the strengthening efficiency of the system (Mionica-2004, Baku-2007, Algiers-2009, Kraljevo-2010, Becici-2010, etc). That was the base for calibration of mathematical model and calculation of the dampers requirements. This is a unique and original approach for design procedure of the dampers. In the same period, we performed shake table tests on the IZIIS and DC-90 shaking tables to investigate the dampers efficiency.

In one of the many inspirational and creative discussions, in 2006, I suggested to Zoran that he should design a special type of damper which will be applied for seismic strengthening of the brick-masonry walls at Canadian Hydro-Power Plants (about 20 m high). He designed a special damper very successfully and we tested its efficiency on a model of wall in scale 1/3 at IZIIS testing laboratory. The finalization of the damper was made in cooperation with Dr. Vladimir Gocevski. Afterwards, this damper was implemented on several power houses in Quebec, Canada. That was, in my opinion, the top achievement of DC-90 system considering the fact that Canadian market is restricted for implementation of foreign technology, especially in the field of seismic protection of vital structures such as power plants.

Another aspect that should be pointed out is introduction and promotion of the DC-90 dampers in European scientific research project PROHITECH realized during the 2004-2008 period and related to seismic protection and strengthening of historical structures by reversible high-tech systems. The information about DC-90 dampers circulated at 16 universities in 12 European and Mediterranean countries. The dampers were tested and verified in the laboratory of Civil Engineering Faculty in Ljubljana.

Establishing the Dynamic Testing Laboratory in Bolech, Beograd, was another ambitious and successful step. It was useful for effectiveness verification of the patented products.

Establishing the summer school for young researchers was also creative approach for distribution of the DC-90 products.

There are some other interesting innovations that Dr. Petrashkovic has patented during the last 25 years. The multi-level damper is one of the very effective ones. The new construction system of lightweight bricks and steel bracings with dampers is also very much innovative and could be applied in earthquake prone areas after experimental verification.

Dr Zoran Petrashkovic always has plenty of ideas about innovations for upgrading the seismic resistance of structures. He has spent a lot of energy and has worked very hard during his period of creative innovation. He has never stopped in his efforts to develop new systems and patents.

Finally, I will terminate my comments with the Zoran's favourite sentence: "We shall work until walk"

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Skopje, October 2013

THOUGHTS ON THE CREATION, DEVELOPMENT AND IMPLEMENTATION OF THE DC90 SYSTEM

FATIGUE IN THE DC 90 DAMPER

In early 2002, when I was the Minister of Urban Planning and Civil Engineering in the Republic of Serbia Government, I received a proposal from the Material testing Institute of Serbia to apply system DC 90 technology in rehabilitation of facilities damaged by the earthquake in Kolubara District. That was the beginning of application and development of a technology which was protected by patent all the way back in 1989.

Thus began collaboration with colleague Petrašković. Now I will focus on the phenomenon of fatigue in the field of a small number of load cycles, i.e. in the field of large dilatations of 5%, 10% or more percent. The size of the dilatations and the small number of cycles characterize the behaviour of structures exposed to earthquake shocks. System DC 90 Damper-devices function on this principle. Without understanding this phenomenon, it is impossible to understand the behaviour of structures under earthquake conditions. In these conditions, the hysteresis behaviour is of a completely different nature compared to the fatigue in the field of large number of cycles. In fact, numerous experimental researches of Petrašković's colleagues prove this, especially when it is about understanding the behaviour of the System DC 90 Dampers. In conditions of large-scale dilatations both the liquid limit and the reinforcement curve slope alter. Cracks form because of material surface imperfections and their propagation, due to the accumulation, leads to the collapse and fracture of materials which constitute DC 90 Damper.

Because of the large dilatations in the field of pressure, the phenomenon of local and global buckling appears, and is solved by specific stability elements which are an integral part of the DC 90 dampers constructions and patent solutions. Thanks to numerous tests on the devices the dependence results between accumulated dilatations and the number of cycles are obtained, as well as the dependence of the change parameters which define hysteresis behaviour. All of this builds on Coffin - Mason research and defines the field of large dilatations. Additionally, new parameters essential in hysteresis modelling when applying Preisach model are entered.

Moreover, based on these findings, new construction systems are being developed, especially new masonry systems for application in seismic conditions. Patent solutions are introduced into engineering practice and have been successfully applied in realization of buildings on four continents.

The range of devices and dampers is increasing for application in construction where it is necessary to control small deformations, as well as to control soft structures in the field of large deformations. The most recent research is based on the research of devices for vibration control in the field of large number of cycles, where the dominant influence is that of wind or of human assault. The line (linear) damper, multilayer damper, srpasti sickle? Rotary damper, rubber vibration damper with a diaphragm, damper/stopper for application in bridge structures, sliding damper and 3D damper are devices that are being researched/tested and most of them have been applied in numerous objects around the world.

Experimental research and new constructions which colleague Petrašković has protected by patents and applied to actual structures open a wide field for scientific research within the spectrum of numerous phenomena. The most prominent are the phenomena related to fatigue in the field of a small number of cycles and other phenomena in fracture mechanics of building materials and structures subjected to cyclic stresses. The current experimental research in Innovation Centre DC90 laboratories and the mathematical modelling of these phenomena are definitely a scientific contribution in the field of experimental fracture mechanics, earthquake engineering and the development of new structural systems and structures complexes.

Prof. Dragoslav Šumarac , PhD.
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ANALYSIS OF MASONRY WALL STRUCTURES

The following portion of this illustrative monograph is focused on modeling the progressive failure in brick masonry. First, an overview of different analytical approaches proposed and used in searching for an appropriate analytical approach capable to adequately describe the behavior of the masonry, is presented. Then, two approaches: (1) Engineering Approach and (2) The Critical Plane Approach are explained in detail.

1. Introduction

Masonry is a traditional construction material which has been used in housing as well as industrial structures for centuries. However, the mechanical response of masonry is quite complex, mainly because it is a composite material having a large number of possible modes of its failure. The mechanical response is further complicated due to a large variability in the mechanical properties of its constituents i.e. bricks and mortar. Furthermore, masonry characteristics are greatly influenced by the quality of workmanship, which is highly variable.

One of the most important tasks for engineers in masonry structures, either new to be constructed or old to be assessed for safety, is to determine the strength of masonry in different loading configurations. For normal steel or concrete structures, the strength of these materials is known from a series of tests. However, in the case of masonry, it is not possible to conduct meaningful tests on a scale that would represent 'masonry'. Moreover, it should be noted that the strength of masonry is required with bed joints in with different orientations, since masonry is an anisotropic material.

The strength of the constituents of masonry can be determined by testing. For new construction, bricks and mortar can be easily tested whilst for existing structures random samples can be obtained and tested albeit with some difficulty of dealing with small samples of mortar. Having established mechanical properties of the constituents, the engineer has to make decisions regarding the strength of masonry in two orthogonal directions. Here the codes of practice may help but for complex structures, there is really no guidance, and more elaborate and sophisticated numerical approaches should be used.

At the initial stage of analyzing any masonry structure it is very important that one of the tasks to be undertaken is to explore the possibility of developing a simple computational procedure (dubbed as Engineering Approach (EA) which could be used as a rough guide to check the structural behavior and validate the results obtained by any complex numerical analysis. A set of simplifying assumptions are made in the EA which are obviously different from those made in the more elaborate and sophisticated numerical approaches and one should not expect perfect matching of prediction of strength under various combinations of stress. Nevertheless, EA when fully developed in the form of bespoke stand-alone computer software could be a useful tool for the use of structural engineers engaged in masonry projects.

Assessment of the mechanical response of existing masonry buildings especially those likely to experience earthquake forces is a complex and challenging task. An earthquake can have a devastating effect in particular on unreinforced masonry structures. The analytical methods proposed by structural engineers for final analysis of masonry are often based on simplistic numerical procedures which cannot realistically address the seismic response of existing masonry structures or the new proposed systems of masonry structures without reinforced concrete walls or frames. The obtained results in some cases are misleading and not correct. This is primarily due to the fact that masonry is a complex composite material, which is anisotropic on the macro scale and has a large number of possible modes of failure. Thus, a rational approach to the problem should incorporate advanced nonlinear formulations that account for the diversity of mechanical characteristics.

- Overview of different analytical approaches

Over the last few decades the numerical analysis of masonry structures has become the main focus of many research programs, leading to a significantly better understanding of the complex behavior of this composite material. This has enabled engineers to develop more rational methods for practical analysis and design while altering the traditional perception of masonry as a decorative material. In the context of numerical modeling, the research has focused mainly on two distinct approaches, that is, at meso and macro scale. Meso models incorporate the properties of the constituents, for example, brick and mortar, as well as the details of the architectural arrangement and therefore can be used to study the interaction of the constituents and the damage propagation pattern under different loading histories. Also, they can be effectively implemented to assess the average mechanical properties of masonry, which can later be used in the formulation of macro models [38, 2 ,3, 46, 22].
The finite element analysis at the mesoscopic level requires, in general, the discretization of both the units and the mortar joints. Such an approach gives the most detailed information about the structural behavior; however, given the enormity of the models emerging in real engineering applications, it is not feasible to implement it for large-scale