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Dynamic Behaviour of High Strength Concrete Elements and Building Structures

Roberta Apostolska[1] and Golubka Necevska-Cvetanovska[2]

Summary

The IZIIS' contribution to development of high quality materials has been seen in realization of several scientific-research projects in the field of high strength concrete in the period from 1992 to 2006. Within the frames of these projects complex laboratory-experimental-analytical investigations have been performed to contribute to definition of the methodology for obtaining high stength concrete exclusively from domestic resources, to investigate joint behaviour of high strength materials and elements in nonlinear range as well as to define dynamic behaviour high strength concrete buildings exposed to seismic actions. The selected results from these investigations are presented in the paper.

Introduction

For wide use of high strength concrete in modern engineering, it is necessary to precisely define its properties and behaviour under different loading conditions and particularly under real seismic effects. To acquire fundamental knowledge of cyclic behavior of high strength concrete elements and structures, comprehensive laboratory-experimental-analytical investigations have been carried out at the Institute of Earthquake Engineering and Engineering Seismology, IZIIS, Republic of Macedonia, (www.iziis.edu.mk). The investigations were carried out in four phases:

(1). First phase, (1992-1996-1998) – the scientific-research project "Development of a Methodology for High strength Concrete", [1].

(2). Second phase, (1998-2000) - project "Methodology for Obtaining High strength Concrete and its Applications", [2, 3].

(3). Third phase, (2000-2003) – project "Dynamic Behaviour of Elements and Structures Constructed from High strength Materials", [4].

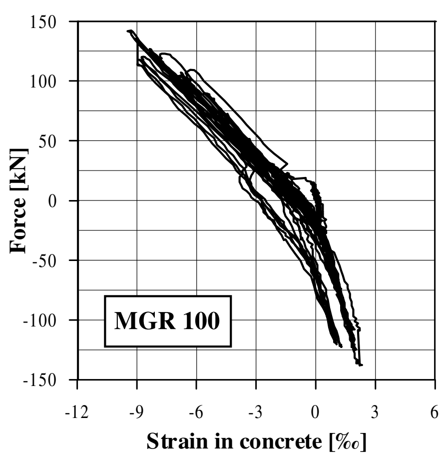
(4). Fourth phase, (2004-2006) – project "Seismic Resistance of High strength Concrete Buildings", [5].

[1]Assist. Prof. D-r, Institute of Earthquake Engineering and Engineering Seismology – IZIIS, University " Ss. Cyril and Methodius", Salvador Aljende, 73, 1000, Skopje, Republic of Macedonia. Email: beti@pluto.iziis.ukim.edu.mk

[2]Prof. D-r, Institute of Earthquake Engineering and Engineering Seismology – IZIIS, University "Ss. Cyril and Methodius", Salvador Aljende, 73, 1000, Skopje, Republic of Macedonia. Email: golubka@pluto.iziis.ukim.edu.mk

Cyclic Behavior of High Strength Concrete Elements - Experimental Research

The original experimental programme consisted of six full scale element models, [2, 6]. The main goal of the investigations was to define the strength and deformability capacity of the elements as a function of several chosen parameters, (concrete compressive strength and percentage and yielding strength of longitudinal and transversal reinforcement). During the tests, the behavior of the models exposed to cyclic loading was observed, from the phase of linear elastic behaviour until cracking of concrete and formation of plastic hinges. Chosen geometry of models dictate that the dominant mode of behavior is flexural bending. Testing of elements were performed in two phases. In the first phase, a three beam models was tested, (MGR60[1], MGR80 and MGR100). The column models, (MS60, MS80 and MS100) were investigated in the second phase. Selected test results are presented through forces-displacements and forces – strains relationships, (fig. 1).



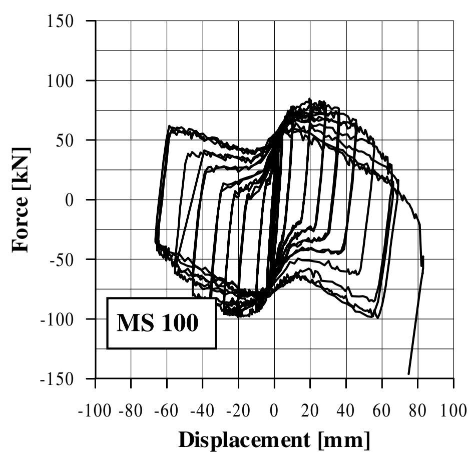


Figure 1: Force-strain and force-displacement relationships, (test registrations)

Analytical Modeling of Cyclic Behaviour of High Strength Concrete Elements

For analytical definition of the bearing and deformability capacity of high strength beams and columns, an original computer program **MPHI-HSC** has been developed, [3]. The obtaining of moments and curvatures completely follows the concept of fiber model analysis of cross-section. Having in mind the specific nature of high strength concete, an original $\sigma - \varepsilon$ relationship for confined high strength concrete proposed by Muguruma, Watanabe et al., [7] has been incorporated in the program.

[1] According to National code, concrete class MB represents standardized compressive strength of concrete based on the characteristic strength tested on concrete cubes (20×20×20cm) aged 28 days.

The computer program MPHI-HSC has been used to analytically define moments, (M), curvatures, (ϕ) and strains in concrete, (ε_c) and steel, (ε_s), at selected points of the beam and column models. Presented further are the selected results of measured and calculated values for characteristics states of strains in concrete and reinforcement, as well as values of curvatures and moments, (Table 1).

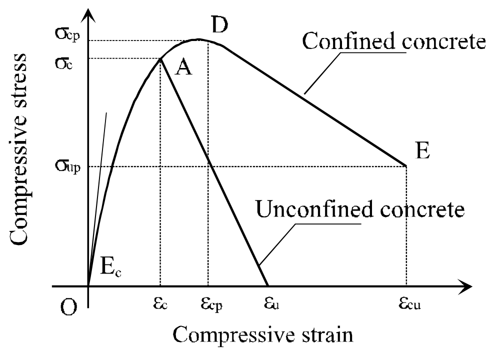


Figure 2: $\sigma - \varepsilon$ relationship of high strength concrete, Muguruma , Watanabe et al.

Table 1: Strain distributions, curvatures and moments for the model MS80

	Experiment	Analysis		Experiment	Analysis	
	ε_c (‰)		Diff. [%]	ε_s (‰)		Diff. [%]
State 1	1.42	1.26	11.3	0.90	1.02	13.3
State 2	2.04	1.78	12.7	2.35	2.57	9.4
State 3	2.72	2.36	13.2	4.00	4.37	9.25
	Experiment	Analysis		Experiment	Analysis	
	M [kNm]		Diff. [%]	Φ [rad/mm]$\times 10^{-5}$		Diff. [%]
State 1	139.6	132.5	5.1	0.885	0.920	3.9
State 2	143.9	136.6	5.1	1.690	1.690	0.0
State 3	127.7	121.3	5.1	2.580	2.610	1.2

The experimentally measured and calculated values for strains, curvatures and moments have shown good correlation.

The main purpose of the performed nonlinear quasi-static analysis is to define nonlinear behaviour of beams and columns constructed of high strength materials exposed to cyclic forces. The analysis was carried out by cyclic displacement time histories at the free end of the models, which correspond to the displacement histories during the quasi-static experimental investigations. The element stiffness matrix has constantly been varied through the analysis according to the formulation of the spread plasticity model and the selected hysteretic model, ("smooth hysteretic model"). Nonlinear quasi-static analyses were performed using IDARC2D, [8] and DRAIN-2DX, [9] computer programs.

The results from the analyses are presented through time histories of displacement and forces, force-displacement relationships as well as histories of strains in concrete and reinforcement, (fig. 3). The correlation between the experimentaly measured and the calculated values are also given. The presented results correspond to the specific set of parameters of the hysteretic model.

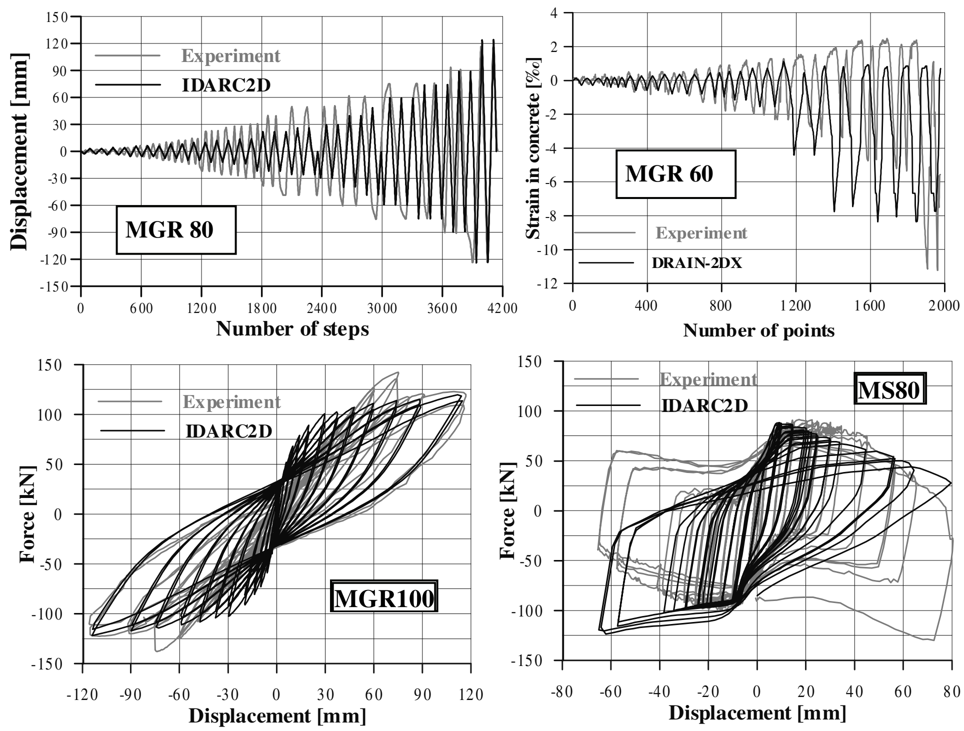


Figure 3: Selected results from the analysis

Dynamic Behaviour of High Strength Concrete Buildings

Presented further are the realized parametric dynamic analyses of the building models design of concrete with compressive strength of 60 to 100MPa, [5]. Four building models were analyzed: 7 storey frame structure – model M1, 15 storey frame structure – model M2, 15 storey structure composed of frames and walls – model M3 and 25 storey structure – mixed structural system – model M4.

The results obtained from dynamic analysis of the models of RC buildings designed of high strength concrete show that the designed models have favorable dynamic characteristics, (fig. 4 and 5).

Results from dynamic response of the model M3 design with concrete compressive strength of 100MPa and different steel grade compare with reference model M3 design from normal strength concrete are presented in table 2.

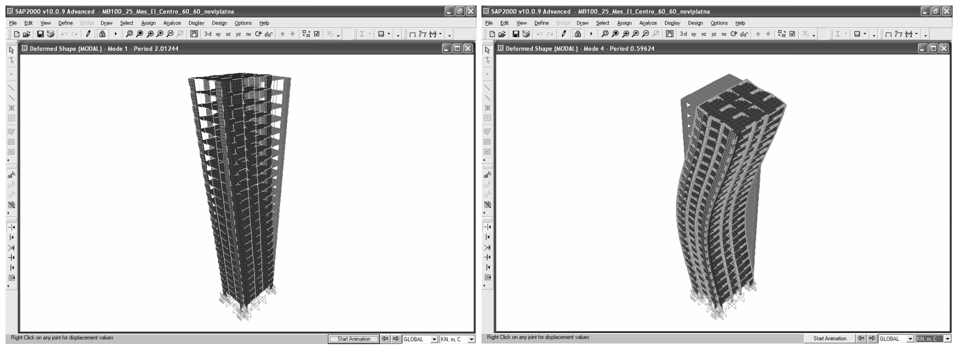


Figure 4: Vibration modes of the model M4

Table 2: Results from comparative analysis of M3 model

	b/h [cm]	f_Y [MPa]	ρ [%]	K	T_1 [sec]	$\Delta^{(*)}_{Y,top}$ [cm]
MB30	**75/75**	**400**	**1.11**	**0.218**	**1.187**	**4.18**
MB100$^{(1)}$	40/40	400	3.6	0.218	1.305	4.49
MB100$^{(2)}$	40/40	1300	1.11	0.218	1.305	4.45

Note Displacement are calculated based on EC8 design spectra, [10]

Dynamic response of the building model M4 exposed to El-Centro earthquake with $A_{\max}$=0.32g are express through time histories of the absolute displacement at the top of the structure, (fig.5).

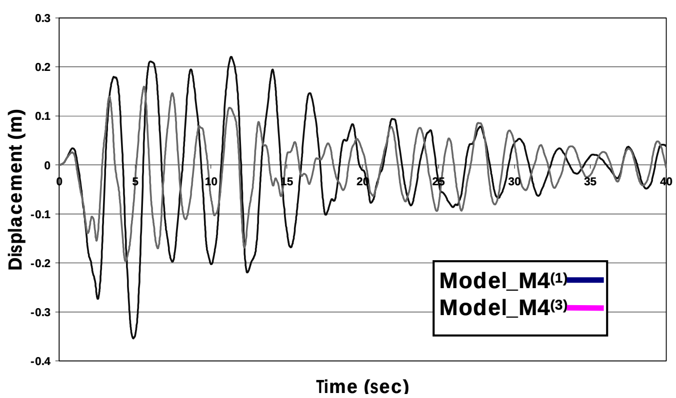


Figure 5: Time histories of top displacement – models M4$^{(1)}$ and M4$^{(3)}$

Note Both models (M4$^{(1)}$ and M4$^{(3)}$) are design with concrete compressive strength of 100MPa. The model M4$^{(3)}$ has additional walls in $x-x$ direction.

Conclusions

- Following the modern world trends, it is already more then 15 years that IZIIS has been working in the field of development and application of high strength concrete in modern engineering practice. An original methodology for production of high strength concrete with compressive strength of up to 100 MPa from domestic resources has been developed. Quasi-static experimental investigations of beams and columns constructed of high strength concrete and steel exposed to cyclic forces have also been performed.
- The results obtained from the performed experimental and analytical investigations carried out in IZIIS have shown that, by appropriate selection of the quality of materials and proper reinforcement and confinement, the elements constructed of high strength materials exposed to cyclic loads exert ductile hysteretic behaviour with favorable energy dissipation.

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