2012 IACSIT Coimbatore Conferences
IPCSIT vol. 28 (2012) © (2012) IACSIT Press, Singapore

Analysis of Instantaneous and Time-Dependent Deflections in Shape Memory Alloy Reinforced Concrete Flexural Members

S.R. Debbarma[1+], and S. Saha[2]

[1]Senior Scientist, CSIR-Central Mechanical Engineering Research Institute, Durgapur, India
[2]Prof. Civil Engineering Department, National Institute of Technology, Durgapur, India

Abstract. The load-deflection behaviors of Shape Memory Alloy (SMA) reinforced concrete (RC) beams have been analyzed and presented in this paper. The influences of the cross-sectional area, reinforcement ratio, yield strength of rebar, and span of beams were considered. Effective moment of inertia, cracking moment, instantaneous and long-term deflections under variable loads on beams were analyzed using ACI 318 (2005), Eurocode 2 (CEN 2002), AS 3600 (2001) and CEB-FIP (1990) prediction codes. Deflection values of SMA reinforced beams were compared with deflections of similar beams reinforced with conventional steel to present the potential of SMAs in restricting instantaneous & long-term deflections. Finally, a new scope of experimental research work is proposed utilizing SMAs as reinforcement in RC flexural members to increase its stiffness and minimize instantaneous & long-term deflections.

Keywords: shape memory alloy, superelasticity, instantaneous deflection, time dependent deflection, reinforced concrete beam.

1. Introduction

Reinforced concrete flexural structures must be designed to satisfy the requirements of both the strength and serviceability limit state. The design for serviceability however is not a straightforward, since the prediction of behavior under sustained service loads is complicated by time-dependent deformations in the composite beams due to creep and shrinkage of concrete. It exhibit strains with age of concrete and causes considerable impact on its performance results in deflection as well as affecting stress distribution. It also causes dimensional change in the material under the influence of sustained loading.

Occurrence of creep & shrinkage in concrete members depend upon the uncertainties of inherent material variations as well as modeling. Studies of uncertainties in creep & shrinkage effects were performed by Bazant ZP [1], Diamantidis D. [2], Madsen HO [3], Li Cq, [4], Choi BS, [5]. As per Bazant [6] the variation of creep and shrinkage properties is caused by various factors commonly classified as internal and external factors. The internal factors are the variations in quality and mix composition of the materials used in the concrete and the internal reinforcement where as external factors are the changes in environmental conditions, such as humidity, temperature etc. Studies on the various individual time effects due to creep and shrinkage in simple supported composite concrete structures can be found in the work of Gilbert [7], Bradford and Gilbert [8]. Despite all these studies and great advances in theories, the time dependent effects in RC structures due to creep and shrinkage have not been controlled rationally.

[+] Corresponding author.
E-mail address: debbarma@yahoo.com.

Therefore it is very important to develop a smart system for reinforced concrete structures, which can minimize internal and external disturbances for structural safety and extension of its service life. Most of the research works conducted in RC structures uses properties of shape memory effects & damping of SMA. However, research findings on the instantaneous and time-dependent deflection behavior of SMA RC flexural members are scare in literature. In this article the results of analytical studies for these deflections in SMA RC flexural members are presented and compared with similar steel RC flexural members. It was observed, that SMA RC beams have more potential to restrict growth of instantaneous and long-term deflections in comparison to similar conventional steel RC beams under similar load.

2. Use of SMA in Civil Structural Applications

Although SMAs have been known for decades, they have not been used much in the civil structures until rather recently. The investigation on rehabilitation properties of intelligent concrete beam reinforced with SMA strands by Di Cui at al.[9] found that on heating the SMA strands by electrical current, the developed cracks on loading can be reduced. The experimental results on deformation behavior and its influencing factors of smart concrete beam strengthen with SMA wires was presented by Jingsi H. [10]. The behavior of concrete beam driven by heated SMA wires using electrical current was studied by Hui L. et al, [11] and results indicate that recovery forces of the SMA wires can decrease the mid-span deflection of the beam, decrease the absolute value of compressive strain and even compress the concrete in the tensile zone. The suitability of using sectional analysis to evaluate the moment-curvature relationship for SMA reinforced section was investigated by Y.I.Elbahy et al [12] and proposed equations to estimate their recommended values. Krstulovic-Opara and Naaman [13] tested SMA composite for their ability to improve reinforcing and prestressing of concrete structures. The deflections of specimens were fully recovered and cracks were hardly visible after unloading. DesRoches and Delemont [14] and Johnson et al. [15] explored the potential use of NiTi rods as seismic restrainers in multi frame bridges. B.Bundara [16] presented the superelastic behavior of SMA on a macro-scale level. The properties for which SMAs can be integrated in civil structures are:

- The large force generated upon returning to its original shape is a very useful property.
- Repeated absorption of large amounts of strain energy under loading without permanent deformation.
- SMA has excellent damping characteristics at temperature below the transition temperature range.
- Excellent property of corrosion resistance (comparable to series 300 stainless steels) and nonmagnetic in nature.
- SMA has low density and high fatigue resistance under large strain cycles.
- It has the ability to be heated electrically for recovery of shape.

However, not all the SMAs have the potential for being used in civil structures due to requirement of special mechanical properties, the specific temperature conditions in civil structures and last but not the least the cost involvement. As the sizes of civil engineering structures are huge, the associated forces are also large and require a substantial amount of materials.

The study of Tamarat.K, [17] shows that Fe-based SMA like Fe-Mn-Si-X, Fe-Ni-C and Fe-Ni-Co-Ti also referred to as shape memory steel or Ferrous SMA have the potential for use in civil structures. The shape memory effects in Fe-Mn-Si containing sufficient amount of Mn were detected in 1982 by Sato et al. [18]. In last decades Fe-Mn-Si based alloys with several additional alloying elements were developed and tested. It was found that 60% to 65% ratio of iron in Fe-Mn-Si-X alloys combines low cost with high strength and high Young's modulus. Corrosion behavior similar to that of stainless steel was achieved by Li. H.J., [19] with addition of 10% chromium and nickel. From the literature of Farjami, S., [20], Lin. C., [21] and Baruj, A., [22] it was found that addition of Al, C, Co, Cu, N, Nb, NbC, V, VN, and ZrC improves shape memory effect. It is reported that the alloy Fe-28% Mn-6Si-5Cr (mass%) with small amount of VN or NbC shows more than 300 and upto 400Mpa stress for constrained recovery. Low-cost SMA has been successfully implemented in bridge rehabilitation by Soroushian et al. [23]. Graesser. E. J., [24] used Ni-Ti for the damping of seismic load successfully.

3. Examples of Deflection Analysis in R.C Flexural Members

3.1 Description of concrete beams

The instantaneous and long-term deflection of eight numbers rectangular RC single span beams was carried out. Among the eight beams four were reinforced with SMA bars and other four with conventional steel bars of grade Fe415. The deflections under various uniform loads in all the simple-supported concrete beams were predicted using available standard model codes. The details of the beams are shown in Table-1.

In the analysis the characteristic compressive strength of concrete was f_{ck} = 35 MPa. The characteristic yield strength & modulus of elasticity of conventional steel bars were f_y = 415MPa and E_s = 200 GPa respectively. The characteristic yield strength & modulus of elasticity of SMA bars were f_{SMA} = 705 MPa and E_{SMA} = 110KN/mm^2 respectively. In calculation of time-dependent deflections the creep coefficient was considered ø = 1.6 and shrinkage strain $\varepsilon_{cs} = 300\text{x}10^{-6}$.

Table. 1: Details of RC beam specimens

Identity	Nominal Dimensions Width x Height x Length (mm)	Type of Rebar	Number and size of Tension Rebar	% area of Rebar
B1-a	125x250x2000	Fe-415	4 nos, 8mm ø	0.64
B1-b	125x250x2000	SMA	4 nos, 8mm ø	0.64
B2-a	125x250x4000	Fe-415	4 nos, 8mm ø	0.64
B2-b	125x250x4000	SMA	4 nos, 8mm ø	0.64
B3-a	250x500x2000	Fe-415	4 nos, 20mm ø	1.00
B3-b	250x500x2000	SMA	4 nos, 20mm ø	1.00
B4-a	250x500x4000	Fe-415	4 nos, 20mm ø	1.00
B4-b	250x500x4000	SMA	4 nos, 20mm ø	1.00

3.2 Instantaneous and time-dependent deflection results

Conducted study was for analyzing typical R.C beam sections with different D (250mm & 500mm), tensile reinforcement ratio ρ (0.64%, 1.0%), type of reinforcement (SMA, steel) span (2000mm, 4000mm) and uniform axial load level. Two identical beam "a" and "b" were analyzed for each combination of parameters. The beam "a" were reinforced with steel bars and beam "b" were reinforced with SMA bars. Model codes used for prediction were ACI 318 (2005) [25], AS 3600 (2001) [26], CEB FIP (1990) [27] and Eurocode 2 (CEN 2000) [28].

The higher yield strength property of SMA bars results in increase in depth of neutral axis of the RC beam from its extreme compression fiber. This influences directly the cracking moment (M_{cr}) of the concrete beam section. The cracking moments of "b" specimens were more in comparison to "a" specimens. Increase in cracking moment of beam section results in increase of effective moment of inertia and causes lesser instantaneous and time-dependent deflections at mid-span due to applied load (or moment).

The mid-span instantaneous and long-term deflections under different uniform load condition for identical beams "a" and "b" using similar prediction model code were calculated and plotted together for comparison in Fig.1, 2, 3 & 4. In these figures the dashed curved lines depict the calculated values for steel reinforced beams and solid curved lines for identical beams with SMA reinforcement. Under similar load, the effective moment of inertia was calculated higher in "b" specimens than in "a" specimens. Comparison of load vs. deflection of SMA reinforced and steel reinforced beams, it was observed that under similar load the growth of deflection was less in SMA reinforced beams. These differences of deflections were found more in RC beams with higher percentage area of reinforcement and in longer span. SMA as a reinforcement have the property to introduce strong driving force inside the concrete structure due to its high yield strength and superelastic properties which restrict the growth of instantaneous and time-dependent deflection.

4. Conclusion

The analysis for deflection behavior of SMA & steel RC beams under various uniformly distributed service loads had been carried out and their differences are presented. The analytical results show that, the mid-span deflection in SMA RC beams were less compared to steel RC beams of identical cross-section, length and grade. High rigidity and superelastic properties of SMA increase this load carrying capacity and reduces instantaneous and long-term deflections. SMA in the RC flexural members acts as a stiffener. Increase in percentage area of reinforcement, cross-sectional area and span of SMA RC beams results in increase of its resistance to the deflection under service load. These analytical results are further required to be validate through experiments.

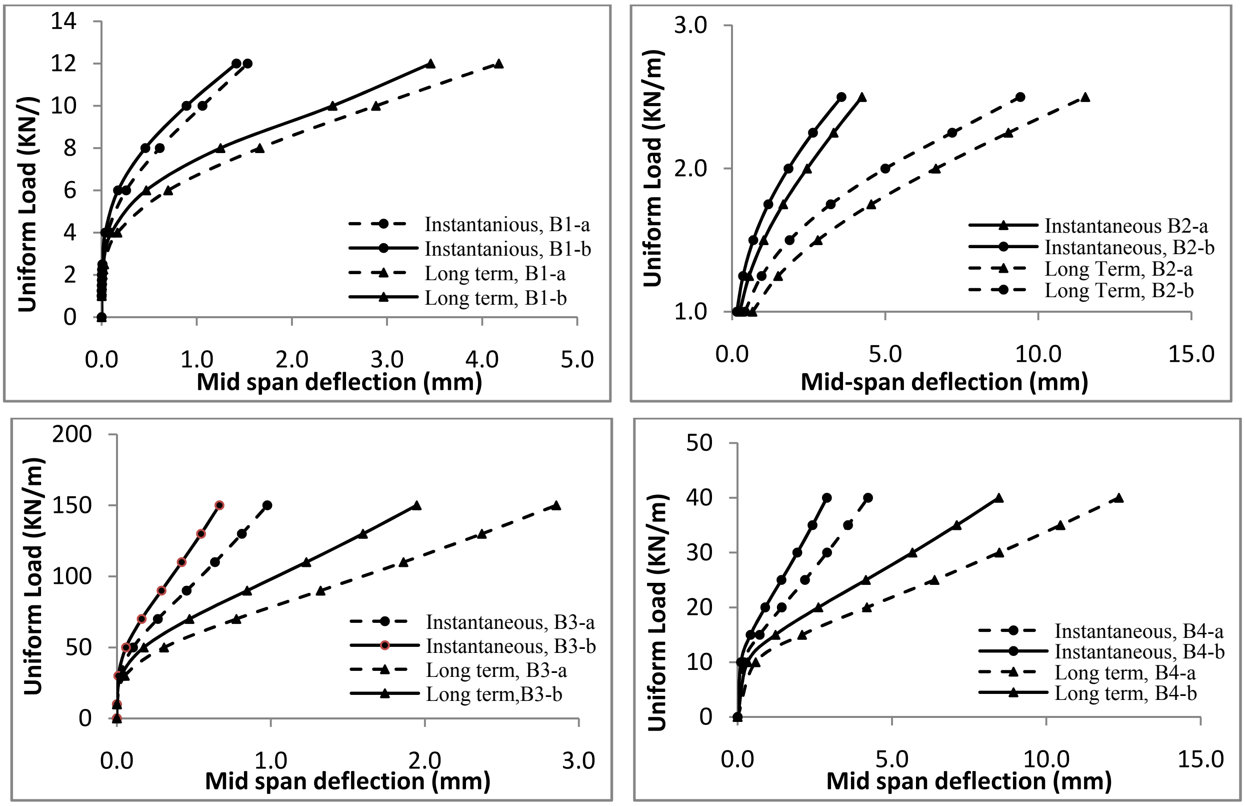
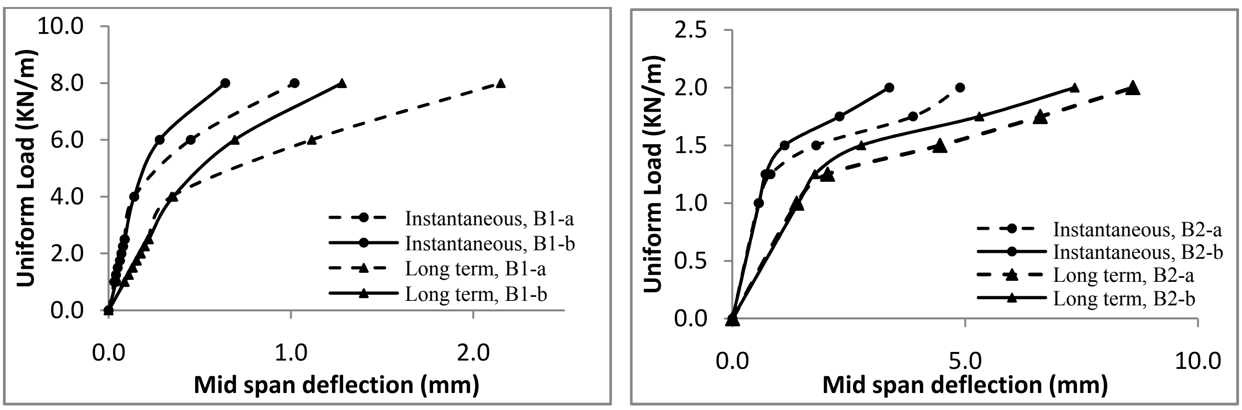


Fig. 1: Load vs. deflection as per ACI 318 (2005)



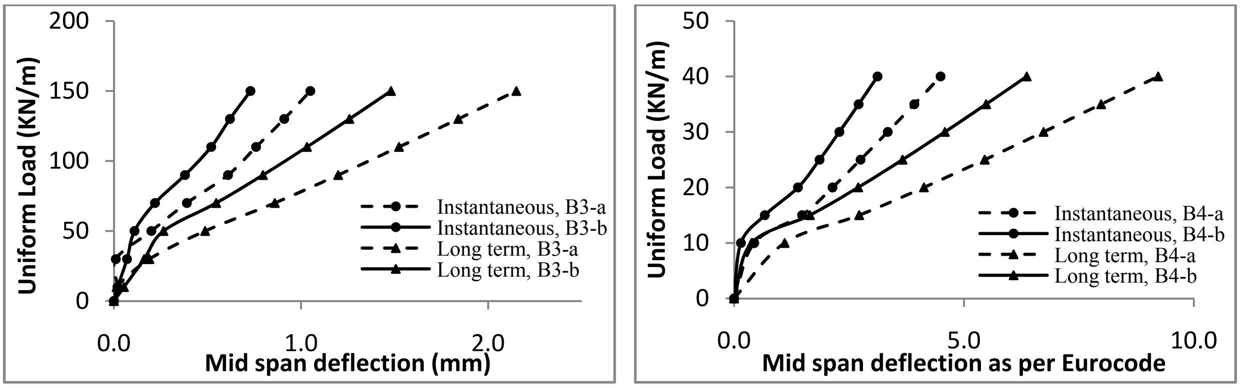


Fig. 2: Load vs. deflection as per Eurocode 2 (CEN 2002)

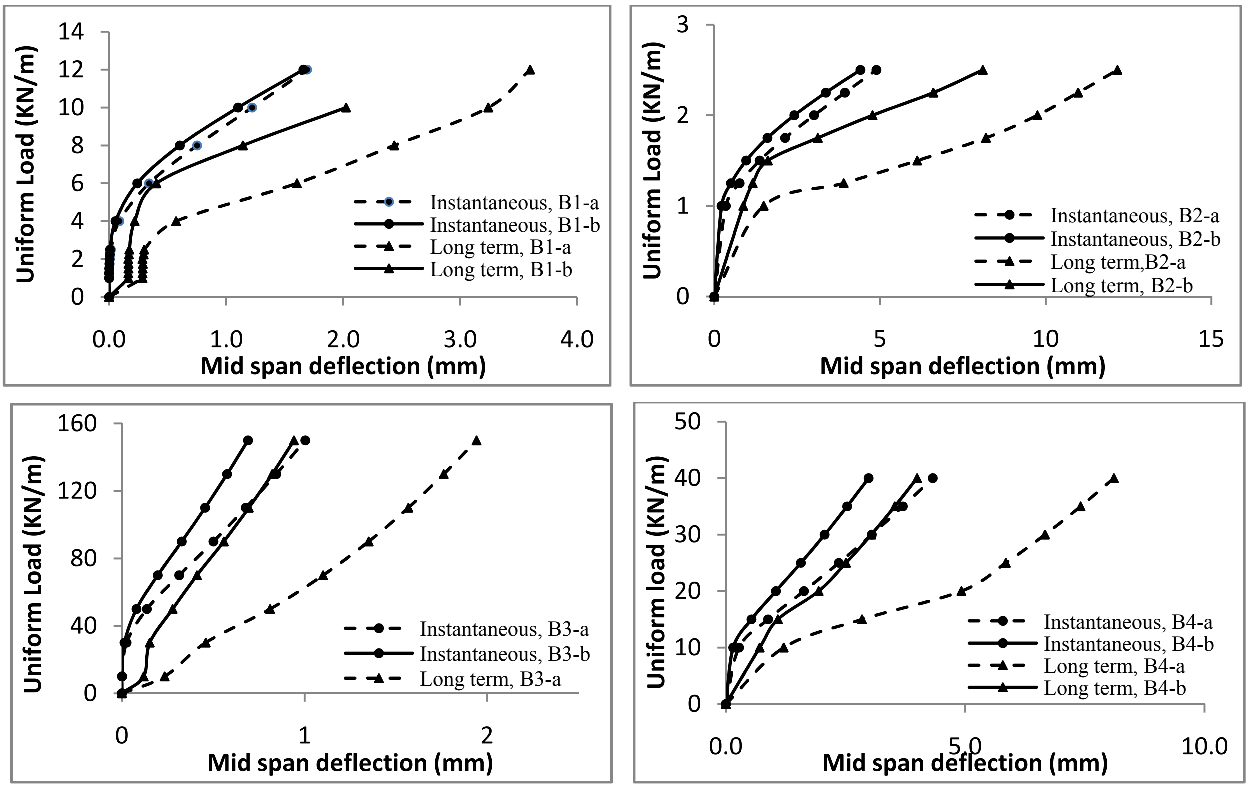
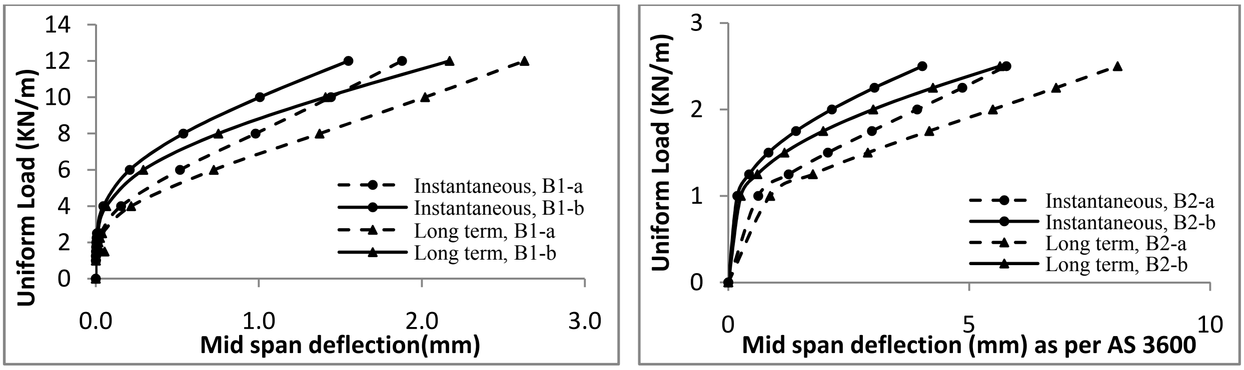


Fig. 3: Load vs. deflection as per CEB (1993)



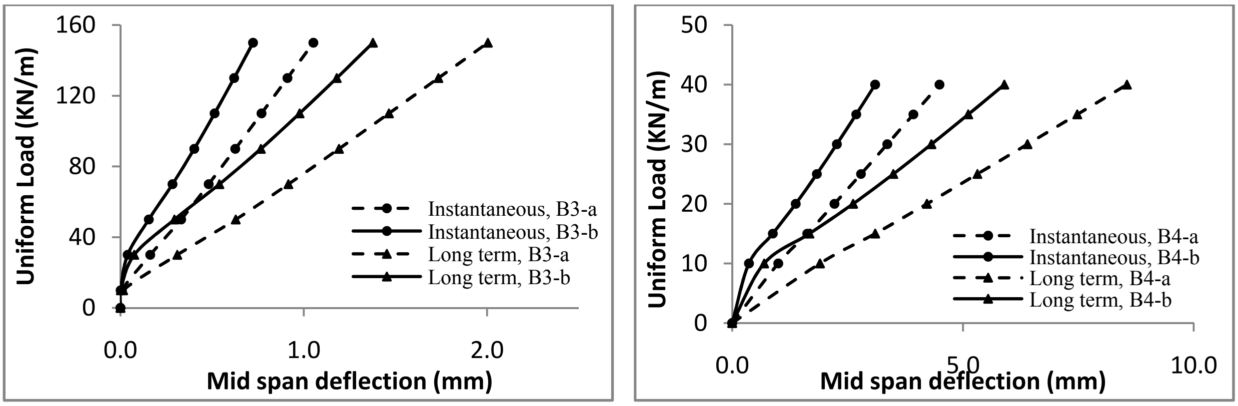


Fig. 4: Load vs. deflection as per AS 3600 (2001)

5. References

[1] Bazant Z.P, Liu K.I. "Random creep and shrinkage Sampling", Journal of Structural Engineering, ASCE;1985:111(5):1113-34.

[2] Diamonds D.madsen HO, Rackwitz R. "On the variability of the creep coefficient of structural concrete." Materials and Structures 1983:17(100):321-8

[3] Madsen HO, Bazant ZP. "Uncertainty analysis of creep and shrinkage effects in concrete structures". ACI Journal 1983:80(2):116-27

[4] Li CQ Malchers R.E. :"Reliability analysis of creep and shrinkage effects" Journal of Structural Engineering, ASCE 1992:118(9):2323-37

[5] Choi BS, Scanlon A., Johnson P.A.,. Monte C., "Simulation of immediate and time-dependent deflections of reinforced concrete beams and slabs". ACI Structural Journal 2004:101(5):633-41.

[6] Bazant, Z.P (1998) "Mathematical Modeling of creep and shrinkage of concrete", John Wiley & Sons.

[7] Gilbert RI. "Time effects in concrete structures", Elsevier;1988.

[8] Bradford, M. A., and Gilbert, R.I. 1989. "Nonlinear behavior of simple supported composite beams." Struct. Eng., 67(14), 263-268.

[9] Di Cui & Ping Guan. "Rehabilitation of Concrete Beam by Using Martensitic Shape Memory Alloy Stands", Advanced Materials Researches, 2011 Vol. 243-249, P 5527-5530.

[10] Jingsi H., Yan X., Zongjin L., "Experiment and Analysis of Smart Concrete Beam Strengthened Using Shape Memory Alloy Wires", Key Engineering Materials, 2008, Vol. 400-402, pp 371-377.

[11] Hui L., Zhi-qiang L. and Jin-ping O., "Behavior of a simple concrete beam driven by shape memory alloy wires", Smart Material Structures, 2006, Vol.15, No.4.

[12] Y.I.Eibahy, M.A.Youssef, M.Nehdi., "Stress block parameters for concrete flexural members reinforced with superelastic shape memory alloys", Materials and structures, 2009 42:1335.

[13] Krstulovic-Opara. N, and Naaman A.E, "Self-stressing fiber composites", ACI Struct.J. 2000, 97(2),335-344.

[14] DesRoches R., Delemont M. "Seismic retrofit of bridges using shape memory alloy" Engg. Strut. 2002, 24(3), 325-332.

[15] Johnson R. Maragakis E., Saiidi. M., "Experimental evaluation of seismic performance of SMA bridge restrainers" REP No. CEER 04-02, Center for Civil Engineering Earthquake Research, 2004, Univ. of Nevada, Reno, Nev.

[16] B.Bundara, M.Tokuda, et al. "Superelastic Tension and Bending Characteristics of Shape Memory Alloys" Journal of Metals and Materials. Vol.6. No.4 (2000). pp 293-299.

[17] Tamarat, K., Stambouli, V., Bouraoui, T. and Dubois, B., (1991) "Structural study of Fe-Mn-Si and Fe-Mn-Cr shape memory steels", J.Phys.IV1(C4), , 347-353.

[18] Sato, A., Yamaji, Y. and Mori, T., (1986) "Physical properties controlling shape memory effects in Fe-Mn-Si alloys", Acta Metall 34920, 287-294.

[19] Li, H.J. and Dunne,D., (1997) "New corrosion resistant iron-based shape memory alloys," ISIJ Int. 37 (6) 605-609

[20] Farjami,S., Hiraga,K., and Kubo,H., (2004) "Shape memory effect and crystallographic investigation in VN containing Fe-Mn-Si-Cr alloys" Mater. Trans. 45(3) 930-935

[21] Lin,C., Gu,N., Liu,Q. and Wen, C., (2003) "Research on low temperature relaxation characteristics in Fe-Mn-Si based SMA" J.Phvs.IV 112 377-380

[22] Baruj, A., Kikuchi, T., Kajiwara, S. and Shinya, N.(2003)."Improved shape memory properties and internal structures in Fe-Mn-Si based alloys containing Nb and C", J. Phys. IV 112 373-376.

[23] Soroushian,P.,Ostowari,K.,Nossoni, A. and Chowdhury, H., 'Repair and strengthening of concrete structures through application of corrective posttensioning forces with shape memory alloys', Transportation Research Record (No.1770)(2001) 20-26.

[24] Graesser, E.J. and Cozzarelli, F.A., 'Shape memory alloy as new materials for seismic isolation', J.Eng.Mech., ASCE 117 (11)(1991) 2590-2608.

[25] American Concrete Institute. ACI (2005), "Building Code Requirements for Structutal Concrete (ACI 318-05) and Commentary (ACI R318-05)", Farmington Hills. Michigan. 112pp.

[26] Standards Australia (2001), "Australian standards for Concrete Structures, AS3600-2001" Sydney, 176p.

[27] CEB. Comité Euro-International du Béton. CEB-FIP model code 1990. Lausanne, (1993).

[28] European Committee for Standardization, CEN (2002), "Eurocode 2: Design of Concrete Structures - Part 1: General Rules and Rules for Buildings", Brussels, pp. 26-35 & 132.