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Seismic performance of self-centring precast post-tensioned bridge columns with SMA bars

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***Abstract*—In this study, the seismic performance of self-centring precast segmental bridge columns with shape memory alloy (SMA) bars are analytically investigated. Nonlinear finite element analyses are conducted. This is shown that the self-centring bridge columns have high lateral seismic demands due to their low energy dissipation which is undesirable. SMA starter bars which have unique re-centring capability against seismic loading are applied in this study. Nonlinear-static analyses show that self-centring precast bridge columns with SMA bars have superior performance in terms of energy dissipation and residual displacement.**

***Keywords*—Precast segmental bridge columns; shape memory alloys; post-tensioning forces; finite element method**

I. Introduction

Precast segmental bridge columns have been appealing subject for many researchers over the past few years. This is due to their rocking mechanism against seismic loading which prevents the formation of the plastic hinge at the basement which leads to less damage and cracks in this area. However, low energy dissipation of this system, limits their application in high seismicity zones. The precast segmental post-tensioned bridge columns were examined experimentally and analytically [1-6]. Hysteretic performance precast segmental bridge columns with central post-tensioned strands and concrete-filled tubes have been investigated in [7]. So far, some researchers have conducted analyses in order to increase energy dissipation of such system. As an alternative solution, superelastic SMA bars can be employed in this system.

In this work, we investigate the employment of the superelastic SMA bars on behavior of self-centring precast segmental bridge columns in terms of strength, stiffness, energy dissipation and residual displacement.

II. Numerical analysis

In order to analyze the hysteretic performance of post-tensioned precast segmental bridge column which exploit shape memory alloy, firstly the analytical results are validated and verified with the experimental results conducted in [4].

A. Loading program

There are four loading steps in the analysis. The first is the post-tensioning of the strands. In the second stage, the PT strands are locked at the ends. At the third loading stage, 890 kN axial loading, which is equivalent of 0.08 $f_c A_g$ representing the bridge deck weight is applied on the top of the column. In the fourth stage of loading, lateral cyclic loading is applied. The cyclic loading program is shown in Fig. 1.

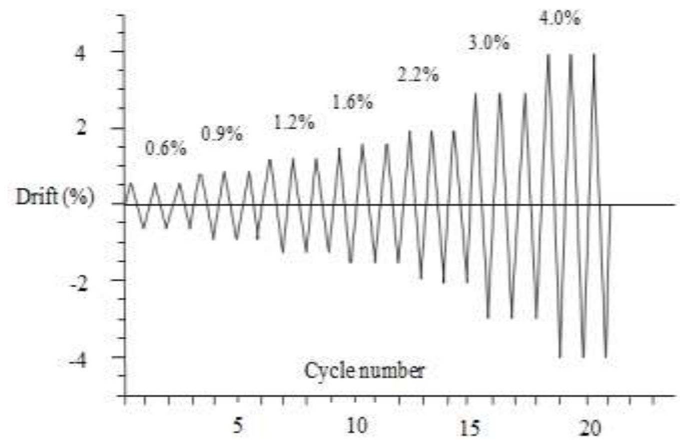

Fig.1 Lateral loading program for the models

B. Modeling of superelastic SMA bars

The material model of SMA is defined using the Auricchio model [8] in the finite element analysis of the ANSYS package. The constants of stress-strain behaviour of this material with their definition are shown in Table. 1.

The Solid185 element is used for modelling of the SMA. In order to provide higher energy dissipation, the SMA bars are bonded in by being passed through corrugated ducts through the first two segments and the footing foundation.

Table.1 SMA material properties used for the models

Constants	Description	Value
σ_s^{As}	Starting stress value for artensite phase (MPa)	414
σ_f^{As}	Final stress value for aretensite phase (MPa)	530
σ_s^{SA}	Starting stress value at the unloading stage (MPa)	380
σ_F^{SA}	Final stress value at the unloading stage (MPa)	130
$\bar{e}_L$	Maximum residual strain (%)	6.2
E	Modulus of the elasticity (MPa)	54200

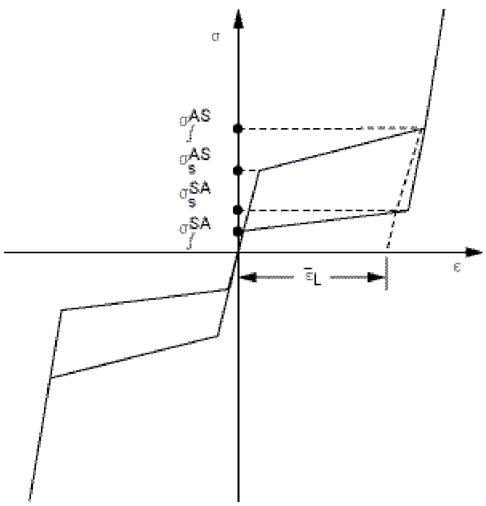

Fig.2 Idealised stress-strain of superelastic SMA [9]

C. Types of elements

The details of the applied elements and their relevant properties and coefficients are as follows:

A Solid65 element is used for modelling of the concrete. This element is defined with eight nodes and three degrees of freedom at each node and has the capability of cracking in tension, crushing and nonlinear plastic deformation. The compressive stress-strain of concrete is obtained using Eqs (1-3) [10].

$$f = \frac{E_C \varepsilon}{1+\left(\frac{\varepsilon}{\varepsilon_0}\right)^2} \quad (1)$$

$$\varepsilon_0 = \frac{2f_c'}{E_c} \quad (2)$$

$$E_C = 4700\sqrt{f_c'} \quad (3)$$

where ε_0 is the strain at the ultimate compressive strength of concrete, E_C is elastic modulus of the concrete (MPa) up to 30% of the compressive strength of concrete.

The Link8 element is used for the mild steel reinforcement. This element has the capability of plasticity, swelling, stress defining and large deflection. Shell181 is used for the steel tube jacketing. This element is appropriate for analysing thin and moderate shells.

During the occurrence of segment uplift, the stiffness of contact elements at the joints has to be set zero and no penetration should be considered while closing the segments at the unloading stages. For this purpose, Contact174 and Target170 with the unilateral flexible surface to surface and penalty method contact algorithm are employed to model the contact between the segments. The coefficient of friction of 0.5 is used for the friction between the surfaces of two adjacent segments.

The Solid185 element is used for the PT strands. This element has the capability of large deflection, plasticity and large strain. The Prets179 element is applied for distributing the pretension force in the tendon. This element has one degree of freedom in one translational direction; it acts between the meshed solid elements. In fact, there are three defined nodes for distributing the pretension force by this element; two created coincident nodes and a third node through which the direction of force should be specified.

Bilinear elastic-perfectly plastic stress-strain has been assumed for the longitudinal, transverse and post-tensioning strands.

III. Validation and verification

Fig. 4 shows a comparison of the cyclic lateral force-displacements of the unbonded segmental sample predicted by finite element method (FEM) in this study and the experiment (EXP). It is clear from the figure that FEM closely follows the experimental results. The difference between the FEM and EXP results is less than 6.6%, which verifies the accuracy of the predicted results in this study.

The unbonded post-tensioned sample was tested up to 3% lateral drift (108.9 mm) because concrete spalling occurs in the second segment at the joint with the first segment area.

IV. Bridge column samples

The self-centring bridge column described above is compared with the precast segmental bridge columns with mild steel and SMA starter bars. The geometry and dimensions of the bridge columns are shown in Fig. 5.

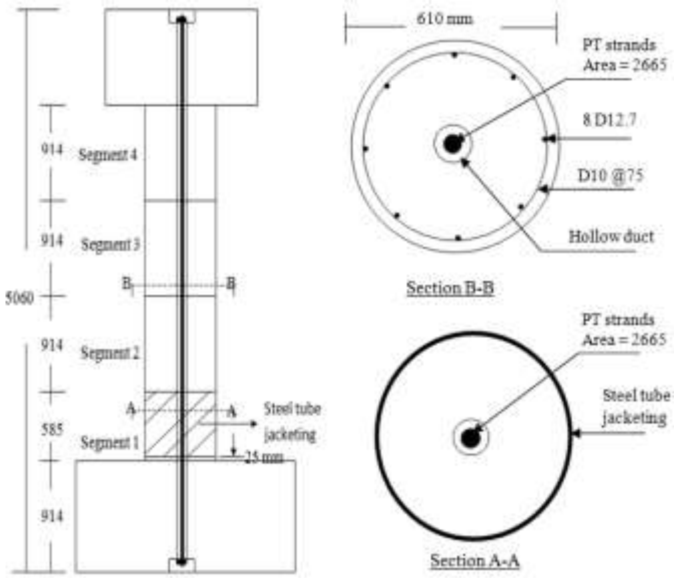

Fig. 3 Self-centring bridge columns

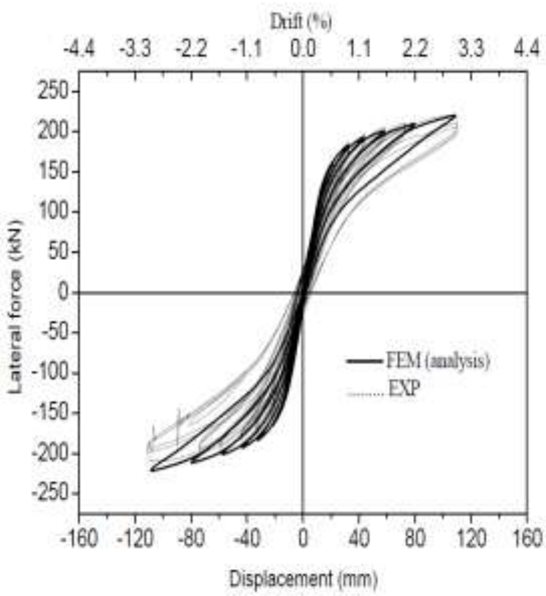

Fig. 4 Load-deflection of EXP and FEM

V. Results and discussion

In this part, the bridge columns with SMA bars (SMA sample) and with mild steel bars (MS sample) are subjected nonlinear-static loading.Fig. 6 compare the hysteretic performance of the Self-centre and SMA samples. The column samples are post-tensioned at 70% initial stress level of PT strands. The figure shows that the SMA sample exhibits lower strength due to the lower stiffness of the SMA bars compared to the Self-centre sample. The equivalent viscous damping of the samples is shown in Fig. 7. It can be seen that SMA sample has the higher level of equivalent viscous damping over the 4% drift level. Fig. 8 compares the cyclic lateral load-deflection of the SMA samples and the MS samples with 32 mm diameter of starter bars. The figure indicates that the MS sample, exhibits higher strength (360 kN versus 300 kN). On the other hand, this sample has higher energy dissipation and has significantly higher residual displacement.

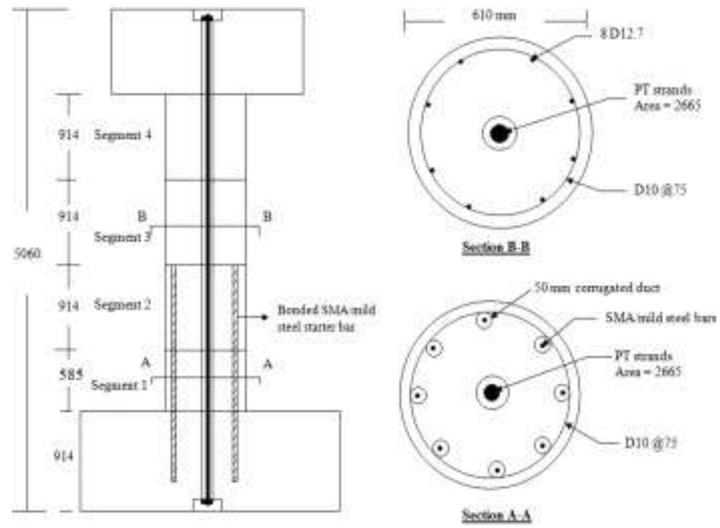

Fig. 5 Bridge columns with SMA and mild steel bars

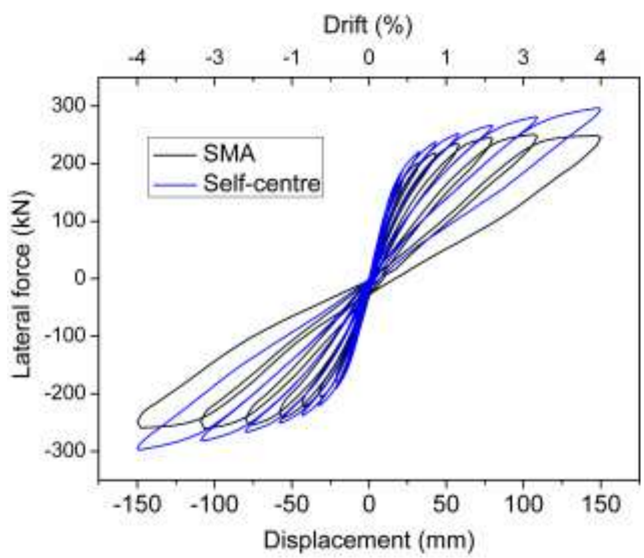

Fig. 6 Cyclic lateral-deflection of the SMA and self-centre samples at 70% PT initial stress

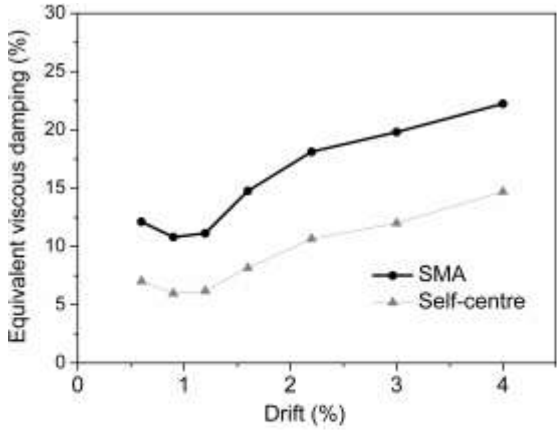

Fig. 7 Equivalent viscous damping of the samples at 70% PT initial stress level

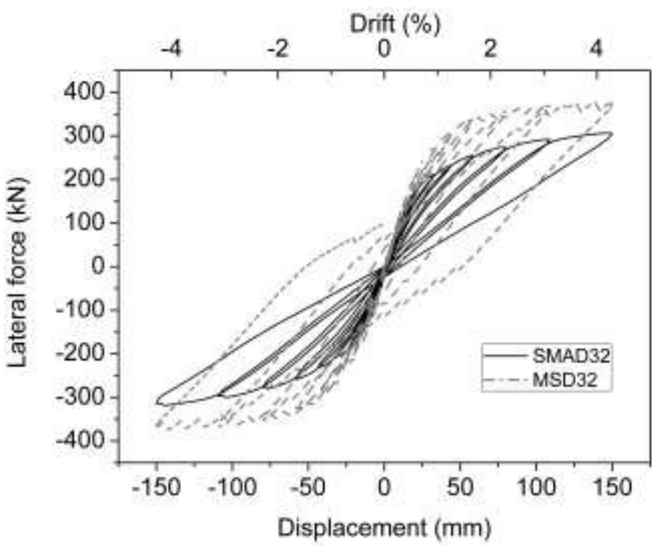

Fig. 8 Cyclic lateral load-deflection of the columns with SMAand mild steel with diameter of 32mm

VI.Conclusions

In this study, the performance of precast segmental self-centring bridge columns with SMA bars under lateral cyclic loading is investigated. The results show that by applying SMA bars, their lack of energy dissipation against seismic loading is improved while keeping the induced damage and residual displacement negligible. We compared the effect of SMA bar size on precast self-centring bridge columns. The results indicate that the samples with the larger diameter SMA bars demonstrate lower stiffness and equivalent viscous damping and higher strength.

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