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USE OF STEEL BELTED AUTOMOBILE TIRES AS TRANSVERSE COLUMN REINFORCEMENT FOR IMPROVED SEISMIC PERFORMANCE

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ABSTRACT

Transverse reinforcement in circular columns provides shear strength against diagonal tension, inelastic deformability through concrete confinement and clamping forces for improved performance of spliced longitudinal reinforcement. An alternative to conventional reinforcement is the use of steel-belted radial automobile tires for improved seismic resistance where applicable. Scrap tires are readily available as waste material; provide stay-in-place formwork during construction, adequate transverse reinforcement for improved seismic performance and corrosion protection for longitudinal column reinforcement. When used for bridge and parking garage construction, they also provide resistance to potential vehicle impact. The use of tires as column transverse reinforcement has been under investigation at the University of Ottawa. A large number of columns were tested under simulated seismic loading to assess their performance. The tests demonstrated improved inelastic deformability, exceeding 4% lateral drift in both flexure dominant and shear dominant columns. The paper presents some of the experimental results while demonstrating the improvements attained with the use of tires as column transverse reinforcement.

Introduction

The majority of column failures observed during recent earthquakes were attributed to poor column behavior caused by lack of inelastic deformability (Saatcioglu and Bruneau 1994, Mitchell et al. 1995, Saatcioglu et al. 2001). Column deformability can be improved by preventing brittle shear failure and confining potential plastic hinge regions through properly

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designed transverse reinforcement. The conventional reinforcement used as column transverse reinforcement consists of closely spaced perimeter hoops, overlapping hoops, cross-ties and circular spirals. An environmentally friendly alternative to conventional transverse reinforcement for circular columns is the use of scrap tires when suitable for a given application.

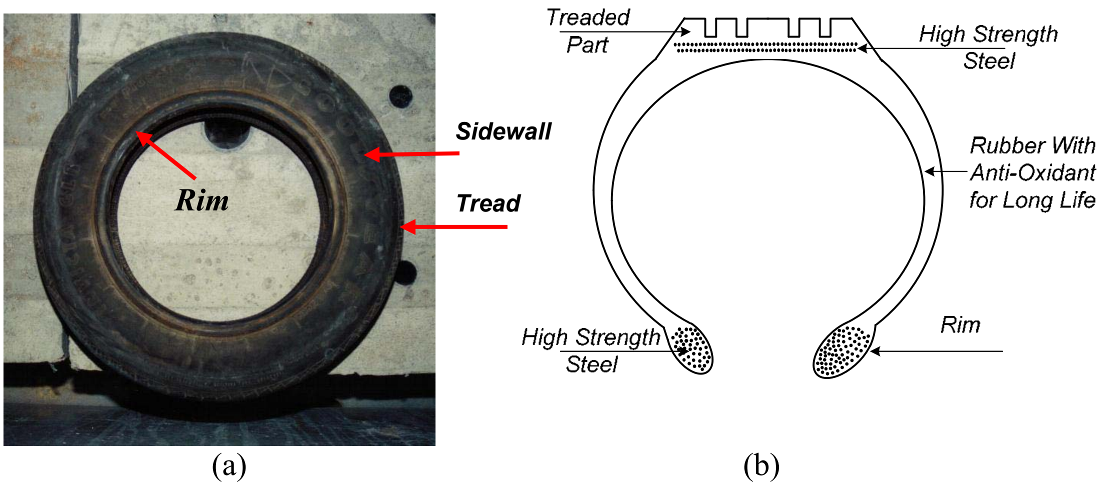
There has been a growing concern over the past twenty years regarding the volume of waste produced by scrap tires, which causes environmental, fire, and health hazards worldwide. It is estimated that in the United States alone more than 200 million automobile tires and 40 million truck tires are discarded every year (Williams 1987). They require large disposal space because of their shape, quantity, and compaction resistance. Furthermore, tires are non-biodegradable and emit toxic fumes when burned for disposal. The mechanical properties of tires remain unaltered even after their life as automobile wheel elements has expired (O'Shaughnessy 1997). While automobile tires appear to have significant amounts of embedded steel reinforcement that may be effective to confine concrete, no research has been conducted to date on the topic. Furthermore, the superior corrosion resistance characteristics of rubber coated steel in tires and their energy absorption capacity under impact loading constitute additional advantages for columns when used for bridges and parking garages where impact may be an issue. This paper reports on an experimental investigation to explore the use of scrap steel-belted tires as transverse column reinforcement.

Tire Types and Constituent Materials

Tires can be viewed under four major categories based on their use; i) passenger tires, ii) truck tires, iii) farm tires, and iv) off-road tires. The passenger tires are the most common of all, representing 80% of the market (O'Shaughnessy 1997). They come in rim sizes of 12 to 15 inches (305 mm to 381 mm), whereas truck tires come in rim sizes of 15 to 24 inches (381 mm to 610 mm). The passenger tires weigh approximately 10kg, and the truck tires weigh approximately 14 to 90 kg. The average weight of steel used in a passenger tire is approximately 0.7 kg.

Three types of passenger tires are used in the automotive industry; i) radial, ii) bias-ply, and iii) bias-belted. The most common type, which was used in the current investigation, is the radial tire. The constituent materials for a radial tire are; fabric, bed wire, and rubber compound. They are fabricated with vulcanized rubber that contains reinforcing textile cords, high-strength steel wire beads, and high-strength steel. Tires have three main parts; treads, sidewalls, and rims. These parts are illustrated in Figure 1(a). The tread contains a number of strong cords coated with rubber. The steel belt or cord under the tread of a radial tire and a rim contains high-tensile steel with high percentage of carbon. The steel in the tread and rim is well protected by a rubber coating. These cords have high ultimate tensile strength of up to approximately 2000 MPa to 2500 MPa. Figure 1(b) shows a typical cross-sectional view of a tire.

Most manufacturers use four wires in a cord, though some use three and others may use up to 10. The commonly used wire has a diameter of 0.25 mm, (area = 0.048 mm^2), producing a cord area of 0.192 mm^2 in a 4-wire cord. The number of cords used in a tread varies among manufacturers though common number of cords is; 14, 15, 17, 20, and 22 per inch (25.4 mm).



(a) (b)

Figure 1. A typical passenger tire; (a) tire components, (b) cross-sectional view

Experimental Program

Preparation of Specimens

The experimental program was designed to investigate the effectiveness of steel belted tires as transverse confinement and shear reinforcement. It involved the construction and testing of large-scale reinforced concrete bridge columns under axial compression and lateral load reversals. The overall research program consists of a large number of column tests involving different size tires, different tie arrangements, different length columns and different levels of axial load (Bugaldian 1999, Bugaldian 2010). Two representative columns, one demonstrating a typical flexure-dominant response, and another one showing the performance of a shear-dominant column, are discussed in this paper to illustrate the salient features of tire-reinforced concrete columns. These two columns were reinforced with passenger tires having 700 mm out-to-out and 381 mm (15 in – size 15) rim diameter, or 550 mm out-to-out and 330 mm (13 in – size 13) rim diameter. The flexure-dominant column (TC-7) had an aspect ratio (the ratio of column shear-span to cross-sectional diameter) of 3.6; and the shear-dominant column (TC-12) had an aspect ratio of 2.2. This translated into a column height of 2500 mm for the 700 mm diameter column and 1200 mm for the 550 mm diameter column and. The column height was measured to the column point of inflection (tip of the cantilever column specimen). The specimens were attached to a steel loading beam of 275 mm depth to transfer the horizontal force. This beam formed a portion of the column top segment, leaving the concrete column portion with either a height of 2225 mm or 925 mm. The specimens represented part of a first storey-building column or a bridge column between the footing and the point of inflection. Each specimen consisted of a column and a footing.

The longitudinal column reinforcement consisted of either 12 - 25.2 mm diameter (No. 25) deformed bars in Column TC-7; or 12 - 19.5 mm diameter (No. 20) deformed bars in Column TC-12 with average yield strengths of 460 MPa and 467 MPa, respectively. This resulted in approximately the same percentage of longitudinal reinforcement in all columns. The longitudinal reinforcement ratios were 1.56% for TC-7 and 1.51% for TC-12. The bars extended 405 mm into the footing, and were bent to form 90-degree hooks with a 500 mm hook extension. Each column had eight Grade 8, 19 mm diameter bolts embedded in the concrete at the top to facilitate the attachment of the loading beam. The longitudinal bars were placed through tire sidewalls by puncturing through the rubber. They were positioned in the middle of the sidewall with some internal cover concrete between the steel and the tire. This is illustrated in Fig. 2. The columns did not have any other transverse reinforcement, like conventional circular hoops.

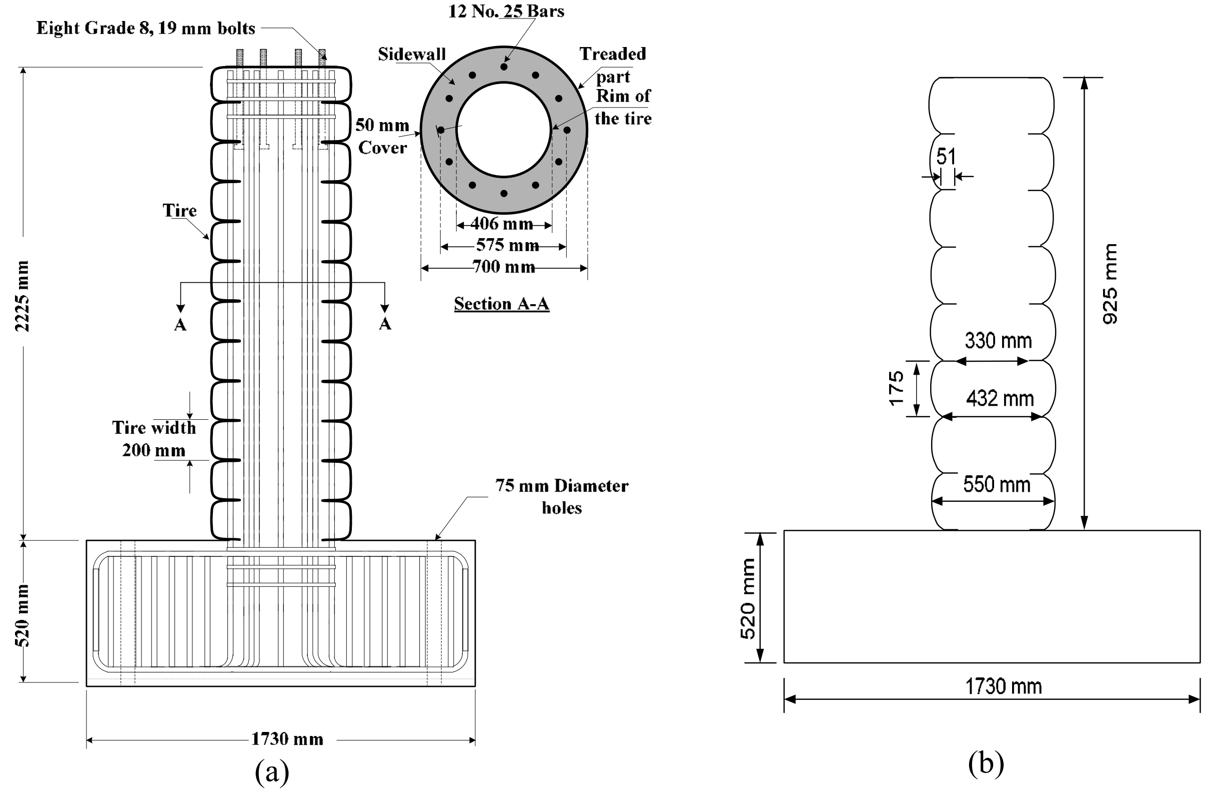


Fig. 2. Geometric Details of Test Specimens; a) Column TC-7 and, b) Column TC-12

A special plywood template was prepared to allow the drilling of holes on side faces for proper positioning of longitudinal reinforcement. This is shown in Figs. 3 (a) and (b). The assembly of column cage was done by inserting pre-drilled tires through the longitudinal bars, on top of each other. This is illustrated in Figs. 3 (c) and (d). Eleven size-16 (16 in rim diameter) tires were used for TC-7 and five size-13 (13 in rim diameter) tires were used for TC-12. The columns were cast from the same batch of concrete. The cylinder strength during the period in which the column tests were performed was 54 MPa.

The columns were tested under constant axial compression and incrementally increasing lateral deformation reversals. The axial compression was applied by means of two 1000 kN capacity MTS actuators. The magnitude of axial compression was equal to 10% and 16% of column concentric capacity P_0 for TC-7 and TC-12, respectively. The lateral load was applied in the deformation-control mode by a horizontally placed MTS actuator of the same capacity. Three cycles of elastic deformations were first applied at 0.5% lateral drift ratio. This was followed by three additional cycles at 1% lateral drift, which corresponded to the approximate yield deformation level. Three deformation cycles were then applied at each subsequent deformation level where each deformation level was increased by 1% drift ratio until the load resistance is dropped by more than 20%. Table 1 provides a brief summary of specimen properties.

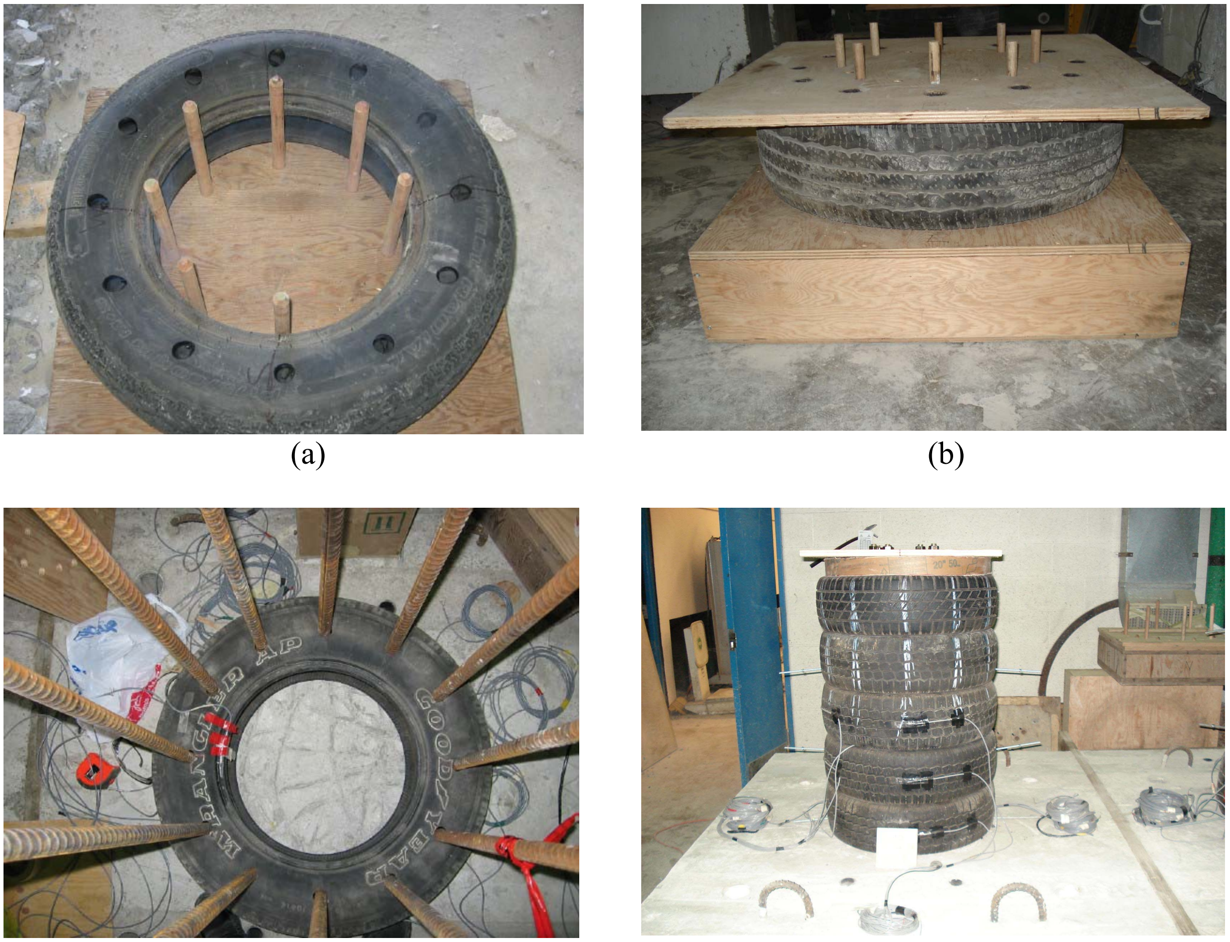

(a) (b)
(c) (d)

Fig. 3 Preparation of column specimens

Table 1. Properties of Test Specimens

Label	Type	Shear Span (mm)	Diam. D (mm)	Tire Size (inch)	Long. Reinforcement		Axial Load	
					Reinforcement Arrangement	f_y (MPa)	P (kN)	P / P_o
TC-7	Flexure	2500	700	16	12 No. 25	460	1900	10%
TC-12	Shear	1200	550	13	12 No. 20	467	1950	16%

Test Results

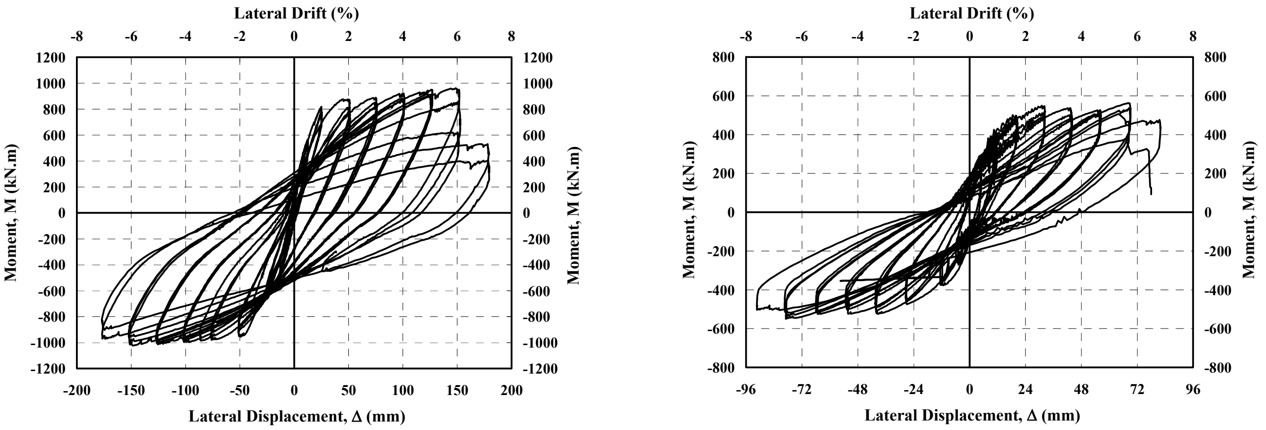
Column T-7 with a high aspect ratio was designed to perform predominantly in the flexure mode. The longitudinal reinforcement consisted of twelve continuous No. 25 (25.2 mm diameter) deformed bars, without splices. There was no conventional transverse reinforcement in the column. The test started with the application of full axial load, followed by lateral load reversals in the displacement control mode. No damage was observed during the first three cycles at 0.5% lateral drift ratio at 12.5 mm displacement and corresponding lateral load of 177 kN. There was no yielding of reinforcement recorded. When the deformation was increased to 1% drift ratio, the strain readings on the longitudinal reinforcement indicated yielding during the third cycle. The strain reading at 175 mm above the footing indicated 0.21% on the west side. Subsequent deformation cycles resulted in increased reinforcement strains, without any visible damage until the end of 5% drift cycles. The strains in the rim of the third tire from the base reached 0.32% during 3% drift cycles. The strains in longitudinal reinforcement at 175 mm below the footing reached 0.47% and 0.55% at the end of 5% drift cycles. The maximum lateral load at 5% lateral drift was 403 kN. At the beginning of 6% drift cyles, high strains were recorded on the treads of the first tire on the west side, and the second tire on the east side. Subsequently, the first and second tires from the bottom started to separate from each other on the east side. There was an increase in the volume of concrete within these tires due to internal damage to concrete. The strains in the rims were increased to 0.48% at this load stage. There was a slight drop in lateral load resistance at the end of the second cycle of 6% drift. Loud sound was heard as the longitudinal reinforcement ruptured on the west side. Subsequently, the second tire ruptured on the East side. There was a significant drop in load resistance at 7% drift ratio. This was attributed to the rupturing of longitudinal reinforcement in tension and the rupturing of the second tire from the bottom. The buckling of longitudinal reinforcement was observed at this stage of loading. The column was able to develop 6.5% lateral drift prior to sustaining 20% decay in strength. At the end of the second cycle of 7% drift the lateral load dropped suddenly to 50% of peak resistance and the test was stopped due to a safety concern. There was extensive damage observed on the east side of the second tire, which was accompanied by the buckling of longitudinal bars. The duration of the test for this column was about two and a half hours.

The hysteretic moment-displacement relationship is illustrated in Fig. 4(a). The relationship indicates that the column developed ductile behaviour and showed stable hysteresis loops. The behaviour was typical of flexure-dominant response with well-rounded hysteresis loops up to 6% drift ratio. The 50% decay in load resistance observed at the end of the second cycle of 7% drift cycles was attributed to the rupturing of the second tire and the buckling of compression reinforcement. Fig. 5 shows Column TC-5 during different stages of loading.

Column TC-12 was a shear critical circular column with reduced shear span of 1200 mm. The longitudinal reinforcement consisted of twelve continuous No. 20 (19.5 mm diameter) deformed steel bars without any splicing. There was no conventional transverse reinforcement. The test procedure was identical to that employed for the previous column. No damage was observed during the three cycles at 0.5% drift ratio with maximum lateral load resistance of 235 kN. At the end of 1% drift cycle, the strains in extreme longitudinal bars reached 0.62%, 0.75%, and 0.56% at the column-footing interface on the east and west sides, and at 135 mm above the footing, respectively. The strains continued increasing with increased lateral drift and reached

1.1 % at the column-footing interface during 2% drift cycles when the strain in the tread of the first tire was 0.35%. Strain measurements at the end of 3% cycles on the second and third tires indicated increased values, developing 0.496%, 0.39%, and 0.49% strains on the east and west sides, signifying control of diagonal cracks in concrete inside the tires, under high shear stress reversals. The strains in the rim of the first tire reached 0.38% and the strain gauges in the first, second and third tire recorded values of up to 0.5% at the end of 4% drift cycles. Some of the strain gauges on the longitudinal reinforcement recorded increased strains of up to 1.5% during 5% drift cycles. The second and third tires started to separate on the east side, and there was a small opening in between the tires on the east side. There was no visible damage in the column until the end of 5% drift cycles. The opening between the tires became more noticeable when the column was loaded to 6% drift. There was little strength decay until the third cycle of 6% drift. As the third cycle was applied, the noise of rupturing longitudinal reinforcement could be heard one after the other and there was degradation in strength as observed from hysteresis loops. Further stretching noise of tires was heard at the beginning of 7% drift, possibly de-bonding from the treaded rubber in the tires. The strain readings on the rim and treads of the second and third tires showed further increase. The steel in the treads of the second tire ruptured on the west side, resulting in a drop in lateral load resistance of about 6%. The progression of damage continued until the second cycle of 7% drift, at which stage the column resistance dropped suddenly by 38%. The subsequent cycle led to more rupturing of the second tire on the west and buckling of the longitudinal reinforcement, crushing of core concrete and rupturing of the third tire on the north side. Testing was discontinued at this stage because of the significant strength decay observed. The duration of test for this column was about four hours.

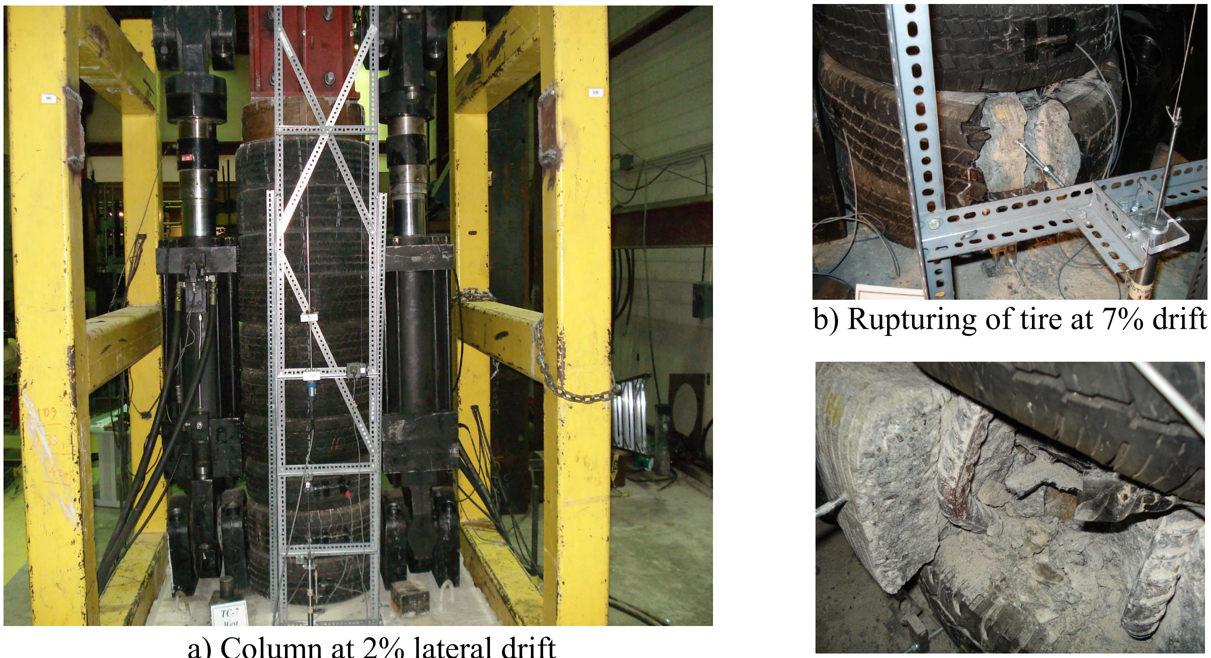
The hysteretic moment-lateral deformation relationship obtained from the test is shown in Fig. 4(b). The relationship indicates that the column was able to sustain the imposed load up to 6% drift. There was no significant strength decay up to the first cycle of 7% drift, but the column developed degradation of strength during the second cycle of 7% drift. The tires in TC-12 provided the required shear resistance while also improving concrete confinement. Fig. 6 shows Column TC-12 during different stages of loading.



a) Column TC-7

b) Column TC-12

Fig. 4. Hysteretic moment-deformation relationships

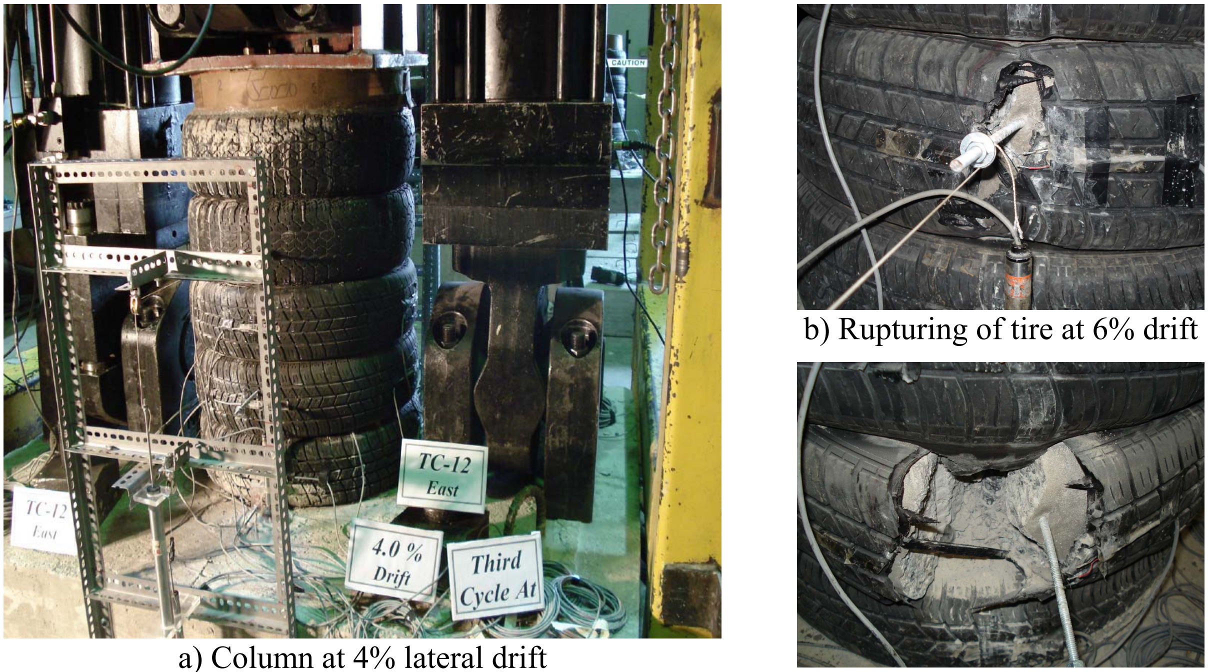


a) Column at 2% lateral drift

b) Rupturing of tire at 7% drift

c) Bar buckling at the end of test

Fig. 5 Performance of Column TC-7 at selected stages of loading



a) Column at 4% lateral drift

b) Rupturing of tire at 6% drift

c) Column at the end of test

Fig. 6 Performance of Column TC-12 at selected stages of loading

Conclusions

The experimental investigation reported in this paper indicates that steel-belted radial tires can be used as stay-in-place formwork, while also providing column transverse reinforcement for shear and concrete confinement. The hysteretic moment-displacement relationships for the flexure-dominant column shows well-rounded stable hysteresis loops, indicating high energy dissipation capacity during seismic response. The column developed its yield moment at approximately 1% lateral drift ratio. Subsequent increases in deformations resulted in increased transverse strains in the first three tires near the footing, resulting from the confinement of compression concrete. The column experienced stable behaviour until 6% lateral drift ratio, and developed flexural failure due to the rupturing of longitudinal reinforcement. This is a typical failure mode in flexure dominant and well-confined columns under low levels of axial compression.

The shear-dominant column was subjected to increased shear stress reversals. The tires provided sufficient transverse reinforcement to control diagonal cracking. The tires experienced high levels of transverse strains, signifying the effectiveness of steel in tire rubber in resisting shear forces. This enabled the column to develop its flexural yield moment. Beyond yielding, the mode of behaviour changed from shear to flexure and the tires continued their effectiveness as transverse reinforcement, this time providing confinement to concrete. The column was able to attain the same level of inelastic deformability, developing up to 6% drift without significant strength decay. The failure initiated through the rupturing of longitudinal flexural reinforcement.

It may be concluded from the observations stated above that steel-belted automobile tires can be used as column transverse reinforcement. Depending on the level of applied load and the type of tire used, the tires may have sufficient strength and deformability to provide shear and confinement reinforcement, improving inelastic column deformability to levels comparable to those obtained from conventionally reinforced concrete columns.

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