THE USE OF STEEL-BELTED AUTOMOBILE TIRES AS COLUMN CONFINEMENT REINFORCEMENT

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ABSTRACT :

Steel-belted automobile tires provide an environmentally friendly alternative to conventional transverse reinforcement in circular reinforced concrete columns. These tires contain sufficiently high percentage of high-grade embedded steel that are effective in confining column concrete. Tires can be assembled on top of each other, either clamped by longitudinal reinforcement inserted through their sidewalls or longitudinal reinforcement placed around the perimeter of the rim. They function as stay-in-place formwork while also providing transverse confinement reinforcement to the compression concrete. The tires also protect the column against corrosion and chemical attacks. When used for bridges or parking structures, they also provide energy absorption against potential vehicular impact. The effectiveness of steel-belted tires as transverse column reinforcement was investigated experimentally by testing near full-size columns under simulated seismic loading. Columns encased in 550 mm diameter tires were tested under constant axial compression and incrementally increasing lateral deformation reversals. The results indicate that reinforced concrete columns, cast in steel-belted radial tires perform favorably, well into the inelastic range of deformations, exhibiting drift capacities of 4% to 6%. Columns with longitudinal reinforcement placed through their sidewalls had higher moment capacity due to the increased lever arm. The concrete between the longitudinal reinforcement and the tires was able to restrain the compression bars against buckling. The results further indicate that column flexural capacity can be computed through the conventional plane-section analysis with appropriate concrete stress-strain relationships that account for concrete confinement and the presence of rubber sidewalls between the layers of compression concrete.

KEYWORDS: concrete columns, confinement, drift capacity, ductility, hysteretic behavior, structural testing.

1. INTRODUCTION

The majority of column failures observed during recent earthquakes were attributed to poor column behavior caused by lack of inelastic deformability. Column deformability can be improved through the confinement of potential plastic hinge regions by properly designed transverse reinforcement. The conventional reinforcement used for concrete confinement consists of closely spaced perimeter hoops, overlapping hoops, crossties and circular spirals. However, the requirements of confinement reinforcement can be labor intensive, uneconomical and potentially leading to construction difficulties associated with the congestion of column cage by closely spaced and vigorously detailed reinforcement.

An environmentally friendly alternative to conventional transverse reinforcement for circular columns is the use of scrap automobile tires for suitable applications (typically for bridges and parking garages). While automobile tires appear to have significant amounts of embedded steel reinforcement that may be effective in confining concrete, their effectiveness and feasibility have not been researched in the past. The paper presents the details and the findings of some of the column tests that form part of a comprehensive experimental investigation that was designed to explore the possibility of using steel-belted-radial tires for column confinement. Specifically, two arrangements of tires with longitudinal bars either placed through the sidewalls or inside the rims are presented with details of sectional analysis for flexure.

2. EXPERIMENTAL INVESTIGATION

The experimental program consisted of tests of large-scale reinforced concrete bridge columns. The columns were designed to utilize standard size tires, while representing part of a bridge column between the footing and the point of inflection. Passenger tires with 13-inch (330 mm) rim diameter (Size 13) were used as column stay-in-place formwork and transverse reinforcement. The cross-sectional diameter of each column was 550 mm. The column height was 2000 mm, measured from the column-footing interface to the point of inflection (shear span = 2000 mm). This height included 1725 mm of reinforced concrete column and 275 mm of steel loading beam placed on top of the column for the application of loads. Figure 1 illustrates the geometric details of test specimens.

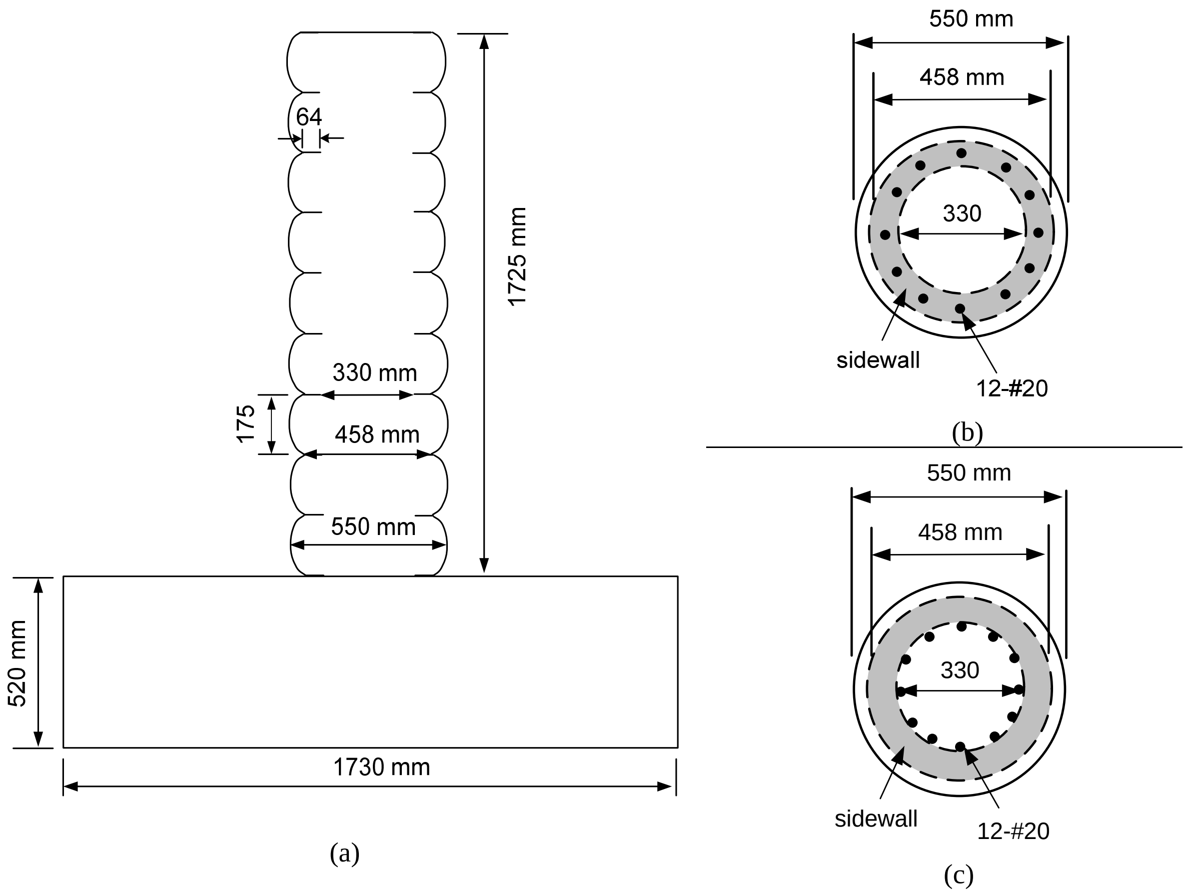
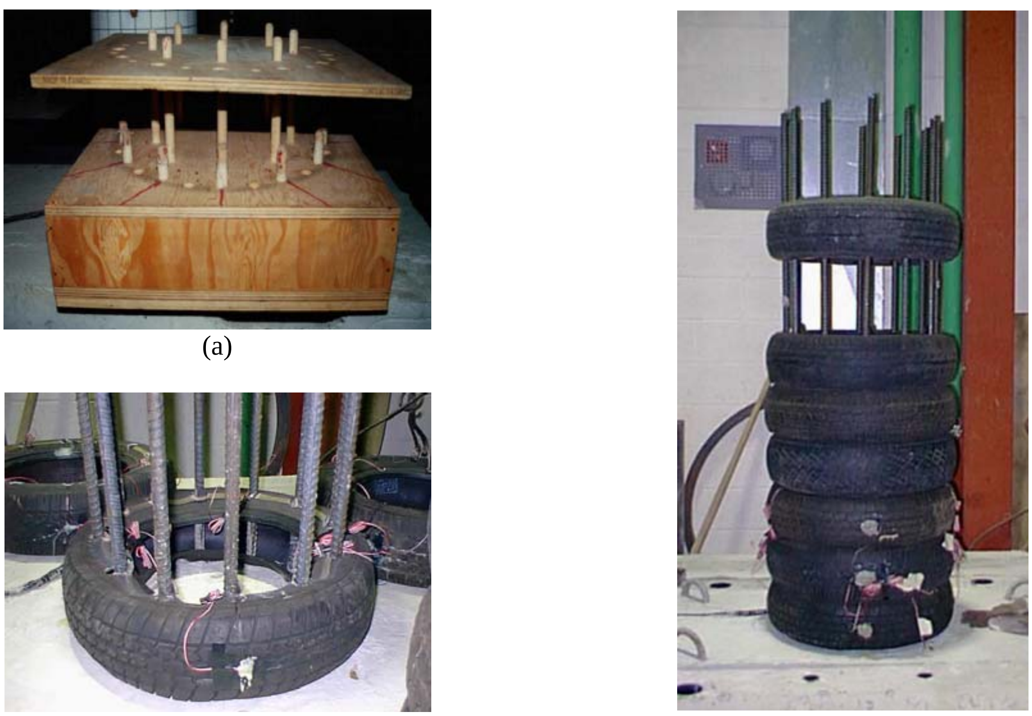


Figure 1 Geometric details of test specimens, a) Elevation view, and cross-sectional views for b) Arrangement 1 and c) Arrangement 2

Two arrangements of tires and longitudinal reinforcement were considered. The “Arrangement 1” had longitudinal bars pass through holes drilled on tire sidewalls as indicated in Figure 1(b). The “Arrangement 2” had bars placed around the circumference of interior tire rims as shown in Figure 1(b). The longitudinal reinforcement consisted of twelve 19.5 mm diameter (No. 20) deformed bars with average yield strength of 453 MPa. They extended 405 mm into the footing and were bent to form 90 degree hooks with 500 mm hook extensions. The bars were all continuous, without any splicing at column-footing interface. The footings were cast first to simulate the actual construction practice. The columns were subsequently cast using a single batch of concrete. The concrete used was normal-density ready-mix concrete with 100-mm slump. Type I Portland cement, natural sand, and 20-mm maximum size aggregate were used with a specified 28-day concrete compressive strength of 30 MPa. The actual concrete strength during the period in which the column tests were performed was 38 MPa. The columns did not have any concrete cover, since they were enclosed in tires that were exposed, although there was concrete betwee longitudinal reinforcement and the interior face of tires.

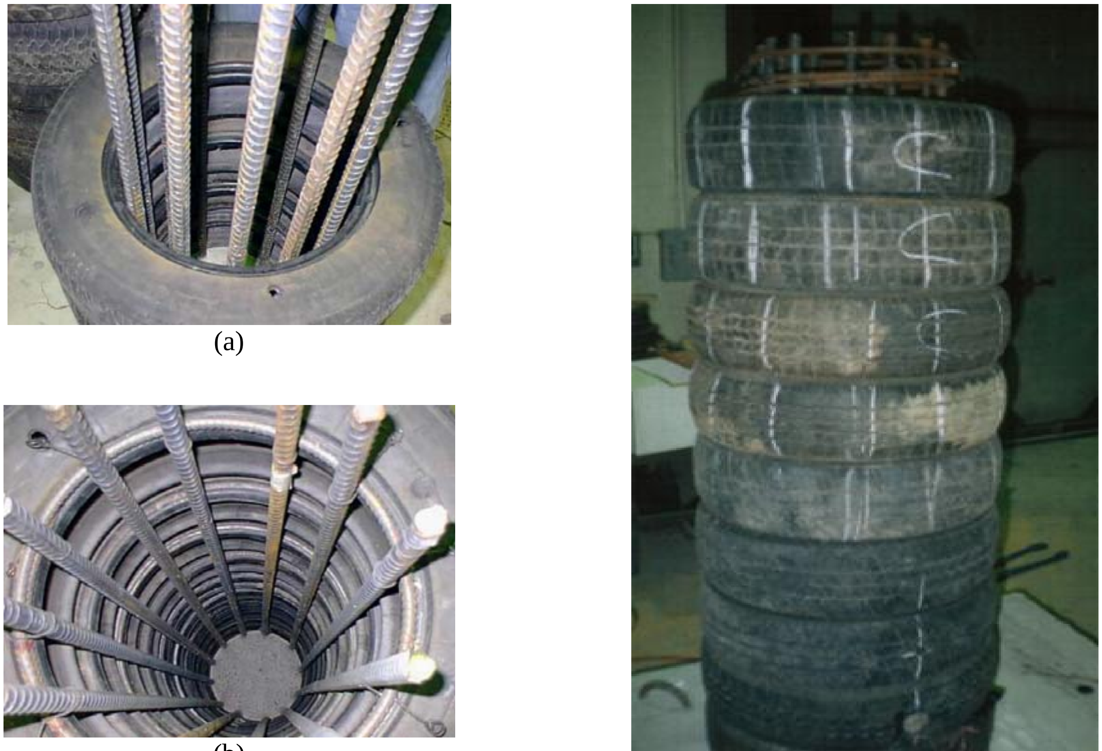
Size 13 Motomaster (Canadian Tire) passenger tires with a designation of P175/75 R 13 were used for Arrangement 1 and the same size Michelin tires were used for Arrangement 2 to build the columns. On the average, the treaded portion of the tires contained 17 steel cords per inch (per 25.4 mm) coated with rubber. Every cord contained four wires. The diameter of each wire was 0.25 mm resulting in an area of 0.049 mm^2. The area of each chord was 4 x 0.049 = 0.196 mm^2. The total steel in treads of each tire was equivalent to a single spiral with a diameter of 5.0 mm and the total steel in each rim of a tire was equivalent to a spiral with a diameter of 4.47 mm. The average ultimate strength of tire (or the ultimate strength of steel in treads since the rubber does not contribute to the strength) was established by taking coupons and testing them in direct tension, as 1905 MPa.

The columns were assembled by placing the tires on top of each other. For Arrangement 1, holes were drilled in the centre of tire sidewalls first to accommodate the column longitudinal reinforcement. The holes were drilled using a cutter steel tube fixed into a drill. A special plywood template was manufactured to align the holes, with dowels made of plywood as illustrated in Figure 2(a). The tires were inserted through the longitudinal bars on top of each other, with longitudinal bars passing through the sidewalls. Selected stages of column preparation are depicted in Figure 2. These columns were labeled as TC-1 and TC-2 and were confined by the tread steel, covering the entire exterior column surface, as well as the rim steel, providing additional hoops to further confine the concrete enclosed by the rims. The columns with Arrangement 2 tires were built in the same manner, except for the longitudinal reinforcement, which was placed inside the rim. These columns were labeled as TC-5 and TC-6. Figure 3 illustrates different stages of construction for Columns TC-5 and TC-6.



(a) (b) (c)

Figure 2 Preparation of specimens TC-1 and TC-2

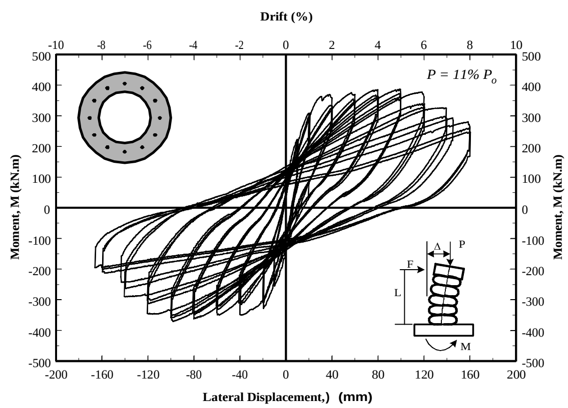


(a) (b) (c)

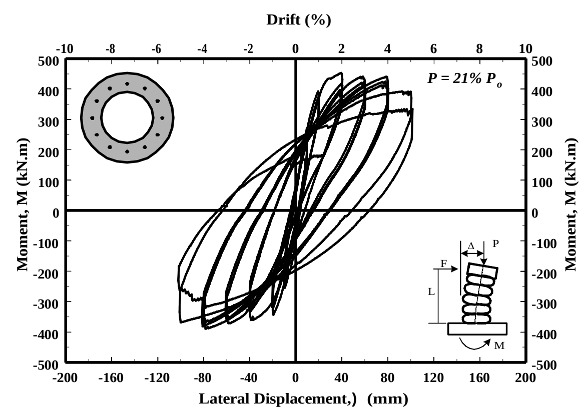
Figure 3 Preparation of specimens TC-5 and TC-6

The columns were tested under two levels of constant axial compressive load, accompanied by incrementally increasing lateral deformation reversals. The axial compression was applied first by two 1000 kN capacity MTS actuators. The axial compression on column TC-1 and TC-6 were 11% of their concentric capacity, P_0, simulating the majority of bridge columns in practice. Column TC-2 and TC-5 were subjected to 21% of column concentric capacity representing a heavily loaded bridge column or a lightly loaded building column. The lateral load was applied in the displacement-controlled 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 approximately to column yield deformation. Three deformation cycles were applied in each of the subsequent load stages in increments of 1% drift ratio until the load resistance dropped more than 20%.

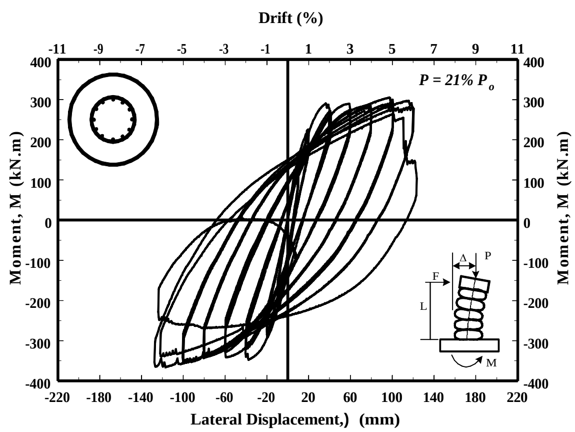
Column TC-1 was tested under a constant compressive force of 1000 kN, which represented 11% of its concentric capacity. It remained elastic during the 0.5% drift cycles. The longitudinal reinforcement yielded at 1% lateral drift ratio with strains in extreme tension bar reaching 0.22% at column footing interface. Yield penetration was monitored by strain gauges placed 135 mm below the footing surface. However, no yielding was recorded by these gauges until after 2% drift ratio was imposed. Transverse strains on the tread and rim of the second tire reached 0.26% and 0.3%, respectively during the 3% drift cycles. This is the strain level that is usually encountered in conventional transverse reinforcement in columns at approximately the same deformation level. While there was no visible damage on the column until the end of 4% drift cycles, both the longitudinal strains in re-bars and the transverse strains in tires continued increasing. The strains in longitudinal reinforcement at 135 mm above the footing reached 0.7% to 0.89% during the first cycle at 4% drift. At the end of 4% drift cycles, the strain in the extreme longitudinal reinforcement at 135 mm below the footing reached 0.37%, indicating significant yield penetration into the footing. When the column was loaded to 5% lateral drift, the first tire from the bottom started to separate from the base due to the formation of a wide crack at column-footing interface. The transverse strain in the tread of the second tire reached a maximum value of 0.42% during the same deformation level. The column survived 6% drift without any sign of severe damage, but most of the strain gauges were damaged due to excessive straining. There was a significant drop in load resistance at 7% drift, which could be attributed to the rupturing of longitudinal reinforcement in tension. The first and second tires from the bottom started to separate from each other during the first cycle at 8% drift, exposing the longitudinal reinforcement. However, there was no buckling of longitudinal reinforcement and the concrete inside the tires was able to control the stability of longitudinal reinforcement. The lateral load resistance dropped by 60% at the end of 8% drift, and the test was stopped due to a safety concern, though there was still no extensive damage visible from outside. The duration of the test for this column was about three and a half hours. Figure 4(a) illustrates the moment-displacement hysteretic relationship. Accordingly, the column survived 6% lateral drift without any significant strength degradation. This is a very high drift capacity, well above the design drift level considered for earthquake resistant construction.



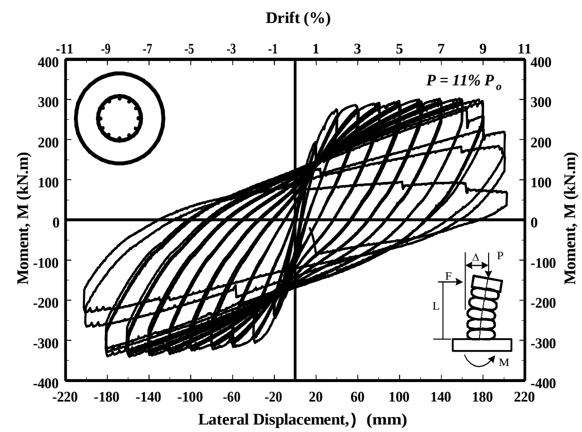
(a) Column TC-1



(b) Column TC-2



(c) Column TC-5



(d) Column TC-6

Figure 4 Experimentally recorded moment-drift relationships

Column TC-2 was identical to TC-1 except for the axial load level which was increased to 1900 kN, corresponding to 21% of its concentric capacity. The lateral load capacity was observed to increase slightly due to the increase in axial compression while the behavior remained the same until 2% lateral drift ratio. The transverse strains measured on the tires showed increased values at 2% drift, reaching a maximum value of 4.4% on the treads of third tire from the base. The longitudinal reinforcement at 135 mm below the column-footing interface yielded at 3% drift ratio, developing 0.24% strain. The second tire from the base showed signs of excessive deformation at 4% drift, developing 0.43% transverse strain. This was attributed to the tendency of longitudinal reinforcement to buckle, which was restrained by the tire. This column survived 4% lateral drift without any drop in lateral load resistance as illustrated in the moment-displacement hysteretic relationship shown in Figure 4(b). The second tire from the bottom ruptured and opened up when the column was forced to deform to 5% drift. When the column was pushed further to start the second cycle, the sidewall of the tire at the column-footing interface ruptured, exposing damaged concrete inside. When the second cycle at 5% drift was applied, the first tire opened up widely, followed by the rupturing of the third tire. The column could not survive the sudden rupturing of the first and third tires from the bottom. The test was discontinued two hours after the start, when 5% drift cycles were completed. The hysteretic moment-displacement relationship indicates that the column showed ductile and stable behavior up to 4% lateral drift, but could not survive 5% drift cycles. The column deformability was reduced significantly as compared to the companion column (TC-1) due to the increased level of axial compression.

Column TC-5 had longitudinal reinforcement placed inside the rims of tires without any transverse ties. This column was tested under a constant compressive force of 1900 kN, which represented 21% of its concentric capacity. The column moment capacity was significantly lower than those of the earlier two columns presented. This is attributed to the reduction in internal lever arm associated with the reinforcement arrangement used. The longitudinal reinforcement yielded at 1% drift ratio. At the same load stage, the third tire from the base developed 0.23% transverse strain in the rim. The column survived 2% drift without any visible damage. Strain measurements on longitudinal reinforcement indicated increased values of 0.77% and 0.99% on the east and west sides at column-footing interface. The strain at 135 mm above the footing reached 0.2% indicating progression of yielding. The column maintained its strength during 3% drift cycles. The strains in the rim of the second and third tires reached 0.42% and 0.32% during the same load stage. The column developed 5% drift without any sign of strength decay. However, there was visible expansion of concrete in the second and third tires, accompanied by the rupturing noise of the individual chords in treads. This column was able to maintain its strength during the first cycle at 6% drift. The noise of rupturing of the steel in tires continued as strain gauges broke loose one by one. The failure was initiated by complete rupturing of the second and third tires on the west side, exposing concrete, and the subsequent buckling of longitudinal bars during the third cycle at 6% drift. The test was terminated one hour and 45 minutes after the start. The hysteretic moment-displacement relationship shown in Figure 4(c) indicates stable behavior up to the second cycle at 6% drift.

Column TC-6 was identical to Column TC-5, except for the level of axial compression which was reduced to 1000 kN, corresponding to 11% of column concentric capacity. The observed behavior during the early stages of loading was very similar to that of TC-5. Yielding was observed at 1% drift ratio. The strains increased during subsequent cycles, reaching 0.85% in the west extreme longitudinal reinforcement at column footing interface. Progression of yielding was recorded during the 2% drift cycles with longitudinal strains reaching 0.2% and 0.65% at135 mm below and above the footing, respectively. The strains in the tread of third tire reached 0.92%. The strains continued to increase with increasing lateral drift. The longitudinal strain at 135 mm above the footing reached 1.3% near the completion of 4% drift cycles, suggesting significant progression of yielding and complete formation of plastic hinging. This was accompanied by the straining of tires within the plastic hinge region, developing transverse strains of approximately 0.20% in the tread of the second tire from the base. There was no visible damage in the column until the end of 5% drift cycles. The crack at the column-footing interface became more obvious when the column was loaded to 6% drift ratio. However, the column maintained its capacity until after the initial cycle at 9% drift ratio. Both the longitudinal reinforcement and the tires started to rupture near the end of 9% drift cycles. The progression of damage continued until the second cycle at 10% drift ratio, at which stage the column resistance dropped suddenly by 50%. The subsequent cycle led to the rupturing of the second tire on the west side, which resulted in the crushing of core concrete. The test was discontinued at this stage two hours and forty-five minutes after the start. The hysteretic moment-displacement relationship is plotted in Figure 4(d), showing stable hysteresis loops up to the beginning of 9% drift cycles. The improvement in behaviour over that of Column TC-1 was attributed to improved support provided for the longitudinal reinforcement by the rims against buckling.

3. FLEXURAL ANALYSIS

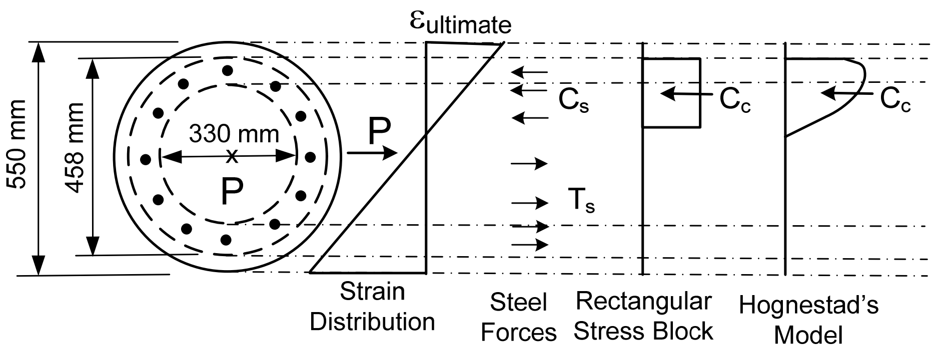
Flexural capacities of test columns were calculated analytically. First, the ACI 318 Building Code approach (ACI 318-05 2005) was employed. The column cross-section considered for this purpose excluded the outermost curved portion of concrete between the treaded portions of tires and the beginning of the sidewalls, since these portions do not come in full contact with each other under compression, as depicted in Figure 1 (the area between the sectional diameter of 550 mm and the sidewall diameter of 458 mm). Hence the cross-sectional dimension was taken as 458 mm as traced by the exterior edge of tire side-walls. This is shown in Figure 5. The analyses using the ACI rectangular stress block and Hognestad's parabola (Hognestad 1951) were conducted up to the ultimate compressive fiber strain of 0.003 at the edge of the side walls (at extreme concrete compression fibre) as per ACI 318-05. The results tabulated in Table 1 indicate higher computed moment capacities than those recorded experimentally. The ACI rectangular block predicted 4% to 14% higher values, whereas the Hognestad's model predicted 7% to 18% higher moment values. This is attributed to the fact that the concrete within the sidewall region do not have the same stress-strain characteristics as the core concrete. The preliminary results obtained from concrete cylinder tests that included layers of tire rubber showed a drastic reduction in concrete strength. This reduction and the confinement of core concrete are two significant effects that have been neglected in the sectional analysis. These aspects of current research are in progress, and need to be well established before a method of analysis for flexure can be proposed for tire reinforced concrete columns.

4. CONCLUSIONS

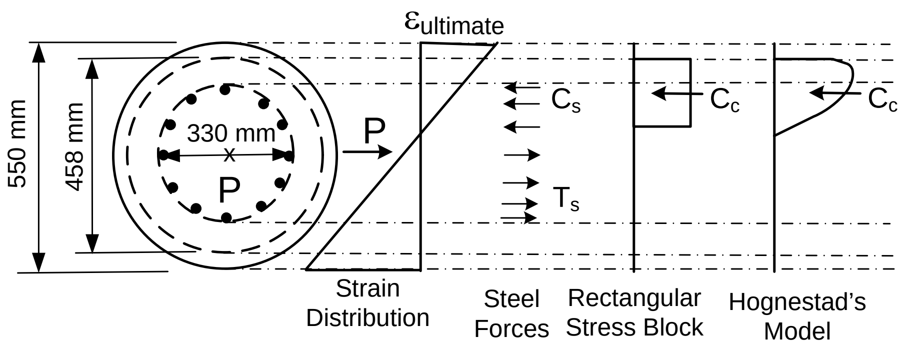
The experimental investigation reported in this paper indicates that steel belted radial tires can be used as stay-in-place formwork, as well as column confinement reinforcement. Inelastic column deformabilities obtained in tire-reinforced columns are comparable to those obtained with conventional reinforcement. The column tests reported in this paper indicate that bridge columns confined by steel-belted radial tires and subjected to 11% of column concentric capacity can develop approximately 6% and 9% lateral drift without a significant loss of strength when Arrangements 1 and 2 were used, respectively. The same columns can sustain approximately 4% and 5% lateral drift for Arrangements 1 and 2, respectively when the axial compression is doubled, indicating that column deformability decreases with increasing axial compression. The results also show higher deformability for columns with longitudinal bars restrained against buckling by the rims (Arrangement 2), although these columns develop lower flexural resistances due to the reduced lever arm of reinforcement. Further research is needed to establish the material stress-strain characteristics of concrete with tire rubber layers (as in the case of the side-wall regions) and the confined concrete stress-strain relationship when the confinement reinforcement is in the form of steel-belted radial tires.

Table 1 Column flexural capacities

Column Label	**Tire Arrangement**	**P/P_o**	**Computed M_n based on ACI318 Block (kN.m)**	**Computed M_n based on Hognestad (kN.M)**	**Experimental Moment, M_n (kN.m)**
TC-1	1	11%	403	410	383
TC-2	1	21%	444	460	425
TC-5	2	21%	390	405	342
TC-6	2	11%	348	357	329



(a) Columns TC-1 and TC-2



(b) Columns TC-5 and TC-6

Figure 5 – Sectional analysis

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