Response of Spun Cast Concrete Poles to Vehicle Impact

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The increased use of prestressed concrete poles for lighting and power transmission have led users to question the safety aspects of such poles. The main questions relate to what happens when a passenger vehicle hits a concrete pole and how prestressed concrete poles behave in comparison with normally reinforced concrete poles under vehicle impact.

The major reason for speculating that prestressed and normally reinforced concrete poles behave differently is that the presence of a relatively high prestressing force may lead to a brittle type of failure upon vehicle impact.

Since it is difficult, if not impossible, to solve such a question theoretically, a series of tests on eleven, full-size poles was undertaken to study the problem experimentally. The tested poles were of a size and height more frequently used for lighting than for power transmission. Thus, the research is more concerned with these lighter and shorter prestressed concrete poles.

PREVIOUS IMPACT TESTS OF POLES

The only reference dealing with vehicle impact on concrete poles known to the authors is a report prepared by the Department of Highways, Ontario, Canada, titled "Impact Testing of Lighting Poles and Sign Supports, 1967–1968." In this study, three reinforced, spun concrete poles were tested under relatively high vehicle speed. The first pole was 15.25 m (50 ft) long and buried to a depth of 3.20 m (10.5 ft) in the ground.

The vehicle, a station wagon weighing 1800 kg (4 kips) hit the pole at 85 km/hr (53 miles per hr) and was brought to a full stop within a distance of 1.20 m (3.9 ft). A maximum deceleration of 27g, where $g = 9.81$ m/sec^2, (32 ft per sec^2) was measured and the damage to the vehicle was considerable. The bottom 1.5 m (4.9 ft) of the pole was totally shattered but the reinforcement did not break.

In addition, the pole broke 3.60 m (11.8 ft) from the top at the point where a circular hoop was spot welded to the reinforcement. No information about the cross-sectional dimensions and the amount and distribution of the reinforcement is given, but the pole wall thickness of the destroyed zone was at least 100 mm (3.9 in.) thick.

The second pole was also 15.25 m (50 ft) long but a break-away base was simulated. The impact speed was 78 km/hr (48 miles per hr) and the recorded maximum deceleration was 12.5 g. Upon impact the pole slid off its base but broke 4 m (13.1 ft) above the base. The test vehicle was severely damaged.

In the third test an 8 m (26.2 ft) concrete lighting standard with an aluminum davit arm was buried to a depth of 1.50 m (4.9 ft), and was hit by a vehicle at a speed of 69 km/hr (43 miles per hr). The pole disintegrated upon impact over a length of about 1.8 m (5.9 ft) above ground level. As in the first test, the reinforcing steel did not break. The upper portion of the pole landed on the car roof, and at the same time the stub was pulled out of the ground.

In all three tests the broken pole fell onto the vehicle resulting in severe damage to the cars. The report recommended that "concrete poles are suitable only for locations where protective barriers or rails are used" to prevent vehicle impact.

OBJECT AND SCOPE OF EXPERIMENTS

The main objectives of the present test series were to find out how reinforced concrete poles with and without prestressing fail under vehicle impact and whether there is a major difference in behavior between these two types of poles.

In addition, it was investigated how the energy absorption of concrete poles could be increased or decreased. Increased energy absorption was expected to be achieved by adding closely spaced spiral reinforcement in the impact zone of the pole and by adding nonprestressed steel to the prestressed concrete poles.

Synopsis

The response of spun-cast reinforced and prestressed concrete poles to vehicle impact is studied in a series of eleven full-sized tests. It is observed that the poles fail due to shear upon impact. Ways to control the impact resistance by different means are discussed.

On the other hand, reduced impact resistance, which may be desirable for the survival of the passengers in the car, was assumed to be achieved by a small wall thickness and a minimum amount of spiral reinforcement. The question whether it is desirable to design a "strong" pole or a "weak" pole is discussed briefly below but is not fully answered.

Of the many variables that affect the resistance and behavior of concrete poles under impact loading, only a very few could be investigated in order to keep the number of tests small.

EXPERIMENTAL PROGRAM

The variables investigated in this test series were:

- Type of longitudinal reinforcement (prestressed or nonprestressed)
- Amount of longitudinal steel
- Amount of transverse steel (spirals)
- Wall thickness
- Vehicle speed

All test poles had the same length of 12.00 m (39.3 ft) and were embedded 1.80 m (5.9 ft) in the ground (Fig. 1). The outside diameter was 360 mm (14.2 in.) at the bottom and 200 mm (7.9 in.) at the top. The poles were spun cast at the Genstar Structures, Ltd., plant in Calgary, Alberta. Details of the production process will be presented later in this article after a discussion of the test variables.

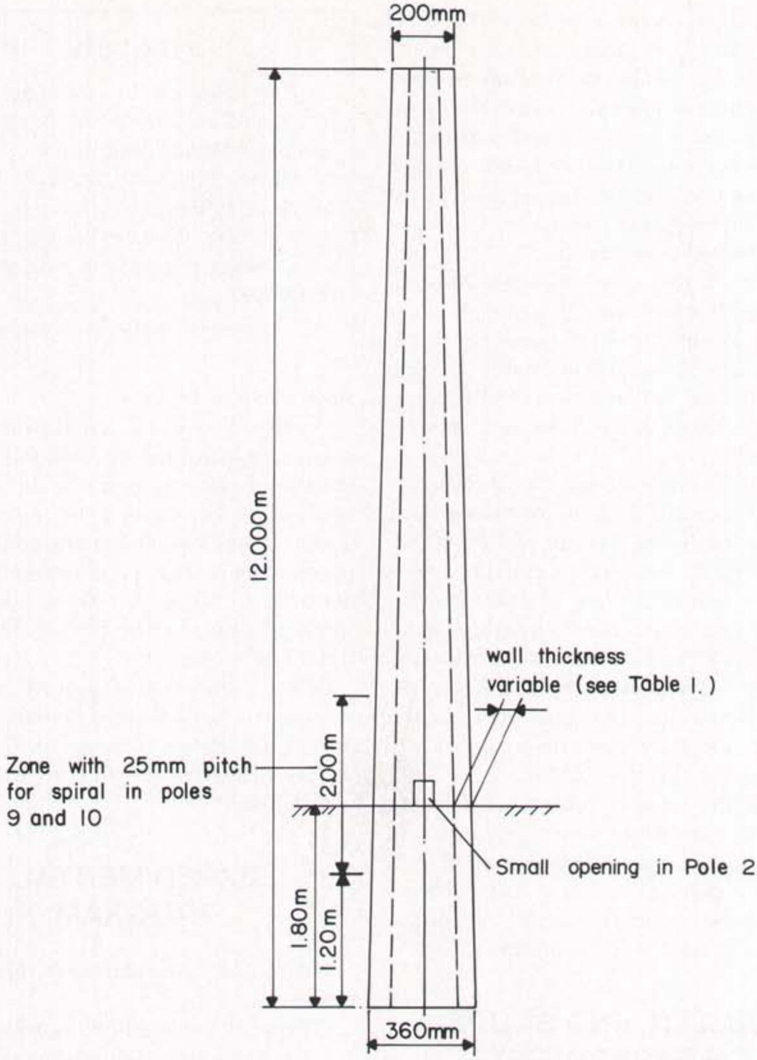

Fig. 1. Pole dimensions.

Other details of the pole are given in Figs. 1 and 2.

Vehicle Speed

The last mentioned variable, namely the vehicle speed, was an involuntary one in that the speed of the first two tests was so high that the specimens were totally shattered. A comparison between similarly tested specimens could therefore not have provided much information and means of strengthening would not have prevented the collapse of the poles.

The first and second tests were run at about 60 and 50 km/hr (37 and 31 miles per hr), respectively, and the rest of the series at approximately 40 km/hr (25 miles per hr), corresponding to about 11 m/sec (36 ft per sec).

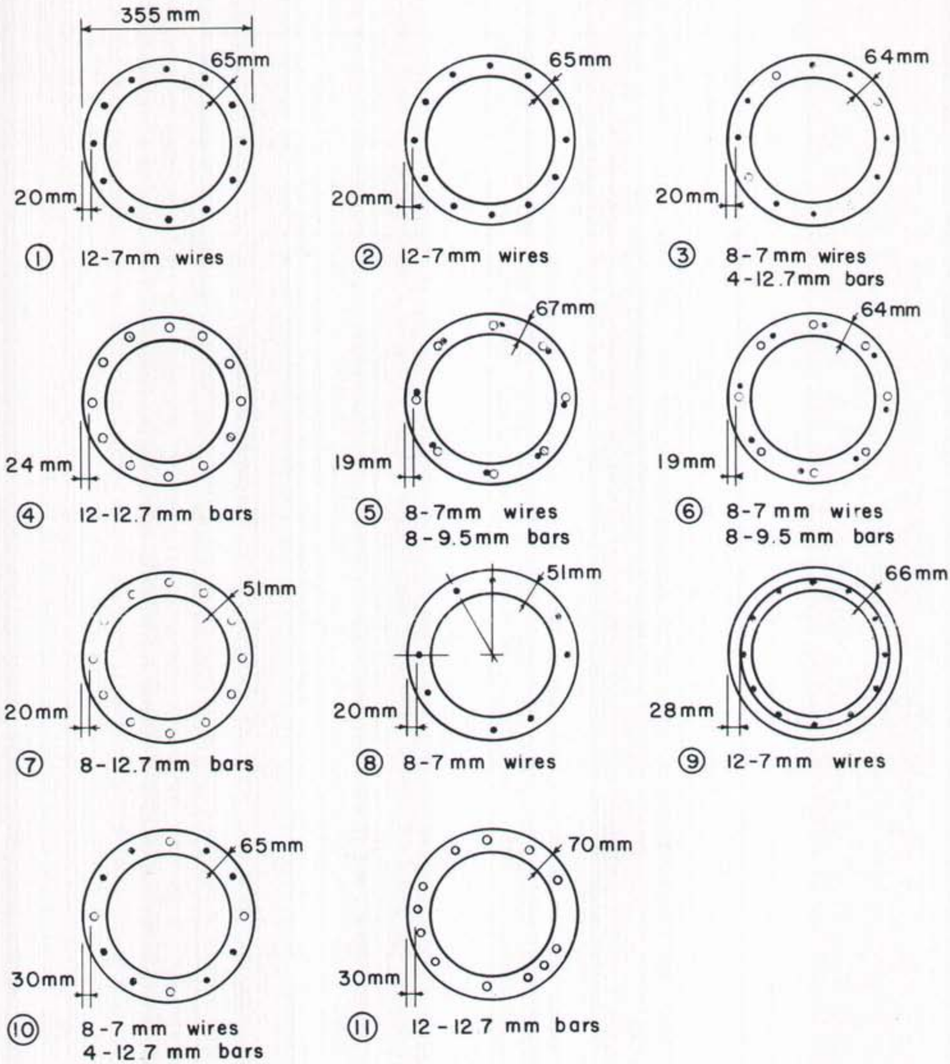

Fig. 2. Cross section of poles at ground level.

Type and Amount of Reinforcement

With regard to the longitudinal reinforcement, three groups of poles were produced:

1. Poles with prestressed reinforcement (four poles)
2. Poles with nonprestressed reinforcement (three poles)
3. Poles with both types of reinforcement (four poles)

The prestressing steel used was 7 mm cold drawn wire, and the nonprestressed bars were either 12.7 or 9.5 mm (½ or ⅜ in.) diameter deformed bars, both with a minimum specified yield strength of 586 MPa (85 ksi).

The number, type and diameter of the bars used in the different test poles are

Table 1. Summary of test parameters.

Test and pole no.	Reinforcement	Spacing spiral rein-forcement mm	Wall thickness at ground level mm	Type of test vehicle	Remarks
1	12 – 7 mm wires	100	65	1967 Ford Custom 500	
2	12 – 7 mm wires	100	65	1967 Plymouth Fury III	Opening at ground level
3	8 – 7 mm wires +4 – 12.7 mm rebars	100	64	1963 Chevrolet Biscayne	
4	12 – 12.7 mm rebars	100	64	1965 Pontiac Strato Chief	
5	8 – 7 mm wires +8 – 9.5 mm rebars	150	68	1959 Meteor Rideau	
6	8 – 7 mm wires +8 – 9.5 mm rebars	150	64	1960 Meteor	
7	8 – 12.7 mm rebars	100	51	1966 Ford Custom	
8	8 – 7 mm wires	100	51	1964 Ford Galaxie 500 XL	
9	12 – 7 mm wires	25*/100	65	1963 Chevrolet Impala	
10	8 – 7 mm wires +4 – 12.7 mm rebars	25*/100	65	1965 Ford Custom 500	
11	12 – 12.7 mm rebars	100	70	1969 Ford Galaxie XL Convertible	

*In impact zone.

Note: 1 in. = 25.4 mm.

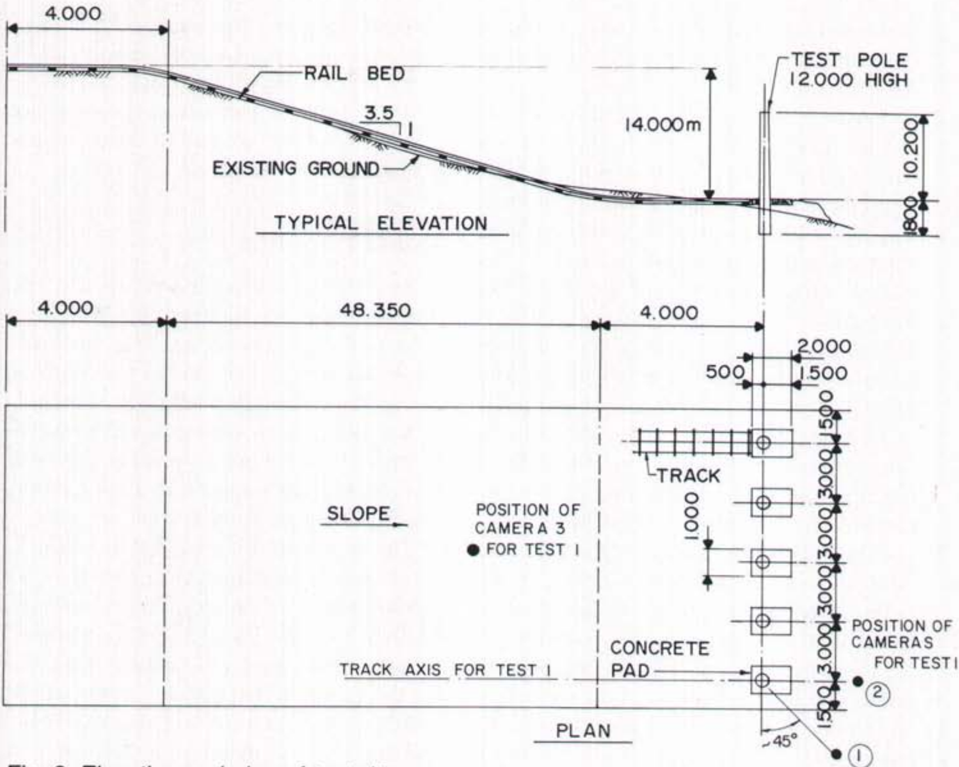

Fig. 3. Elevation and plan of test site.

summarized in Table 1, together with other relevant test parameters.

The prestressing wires were all initially stressed to 1120 MPa (162 ksi) which corresponds to 70 percent of their tensile strength. All the prestressing wires and all the 12.7 mm (½ in.) bars extended over the full length of the poles; however, the 9.5 mm (⅜ in.) bars of Specimens 5 and 6 extended only over the lower 6.50 m (21.3 ft).

The spiral reinforcement in all the poles consisted of 3.4 mm (⅛ in.) diameter (10 gage) cold drawn galvanized wire. Only one single spiral was provided and the spacing in most poles was 100 mm (3.9 in.) except in Poles 5 and 6 where the spacing was 150 mm (5.9 in.) and in Poles No. 9 and 10 where the spacing was only 25 mm (1 in.) in the impact zone. Details of the arrangement of the longitudinal and transverse steel are given in Fig. 2.

Wall Thickness

The wall thickness of the majority of the poles was approximately 65 mm (2.6 in.) with three exceptions: Poles 7 and 8 with the smallest amount of reinforcement had a wall thickness of only 51 mm (2 in.), and Pole 11 had a wall thickness of 70 mm (2.8 in.). The thicknesses of all poles are listed in Table 1. These thicknesses are average values of four measurements at ground level recorded after completion of the test.

Test Site and Test Setup

The test site selected had a natural slope such that the test vehicles, mounted on a trolley, reached the desired speed by gravity. In order to reach the desired maximum test speed of 60 km/hr (37 miles per hr), a vertical drop of 14 m (46 ft) was required (Fig. 3). A narrow gage track and a trolley fabricated with the axles of an old mining car were used to guide the test vehicles to their target.

For the trolley, a pair of axles of an old mining car was mounted underneath a hardwood rectangular frame (Fig. 4). The top of the two longitudinal beams of the frame was greased which allowed two loose planks supporting the car to slide relative to the trolley. At the front end of the frame two hardwood beams were mounted which served as a buffer to protect the cast iron wheels from a possible impact with the concrete pad cast around the base of the poles.

In order for the cars to hit the poles at the desired level (i.e., with the wheels touching the ground), the track just before the pole had to be depressed by approximately 0.25 m (0.82 ft) (see Fig. 5). This depression made it possible for the buffer of the trolley to hit a wooden plank fixed to the ground at about the same time the car hit the pole. The car impact was thus not influenced by the trolley and the cars could sit loosely on the trolley without requiring any fastening. All cars had an approximate mass of 1500 kg (3.3 kips).

The poles were erected 3.0 m (9.8 ft) apart (Fig. 3) in two groups, first five and then six poles, and the tracks were moved sideways from pole to pole. To provide a relatively rigid support at the base of the pole, a 1.00 m × 2.00 m and 0.15 m thick (3.3 × 6.6 × 0.5 ft) concrete pad was cast around each pole. The test site prepared for the first test is shown in Fig. 6.

Measurements

The Ontario tests showed clearly that concrete poles are shattered when hit by a vehicle. For this reason any strain measurements would have been rather meaningless. It was, therefore, decided to rely entirely on the visual information gathered by means of high speed cameras, and on the measurements of the impact speed and destruction observed on the poles and vehicles.

The car speed was recorded by means of an electronic digital counter capable of recording time with an accuracy of one millionth of a second. This counter was switched on and off by electrical contacts triggered by the trolley. The distance between the switches was measured to 1 mm (0.039 in.) and thus the time measurement allowed the determination of the impact speed rather accurately.

The distance from a fixed point on the ground to the concrete pad was measured

Fig. 4. The trolley.

before and after each test to determine the pole base movement caused by the impact.

Three film cameras were used to record the event. Camera 1 was a FASTAX high speed camera which was set at a rate of 500 frames per second. The location of this and the other cameras is indicated in Fig. 3. A LOWCAM camera (Camera 2) was set in front of the pole recording the impact at 128 frames per second and a third camera (64 frames per second) followed the event from beginning to end.

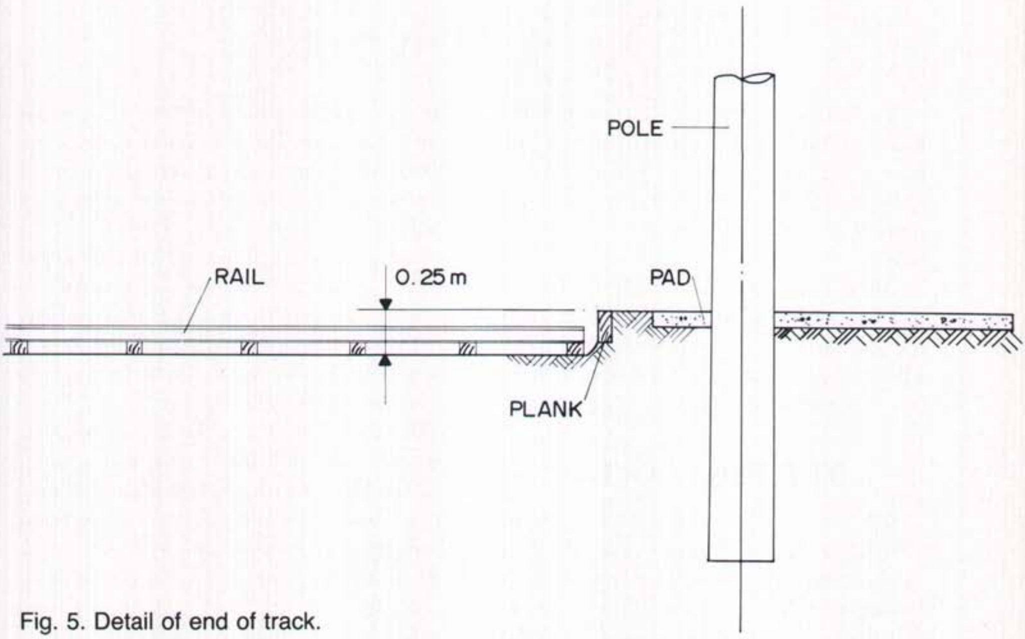

Fig. 5. Detail of end of track.

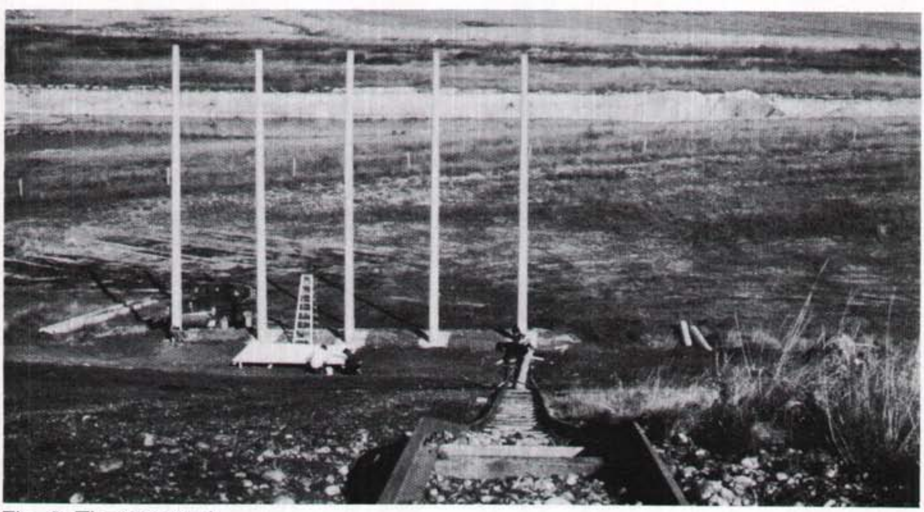

Fig. 6. The test track.

Table 2. Concrete mix.

Cement	483 kg/m^3	(815 lb/cu yd)
Water	178 kg/m^3	(300 lb/cu yd)
Water-cement ratio	0.367	
Sand	414 kg/m^3	(700 lb/cu yd)
Gravel	1243 kg/m^3	(2100 lb/cu yd)
Water-reducing agent	Pozzolith 322 N, 0.92 l/100 kg cement	
Air-entrainment agent	MBRV; 0.125 l/100 kg cement	

Note: 1 lb = 4.448 N; 1 kip = 453.6 kgf; 1 l = 3.785 gal.

To be able to assess the horizontal movements of the pole during the impact, a white backdrop 2.40 × 3.60 m (7.9 × 11.8 ft) with a 200 × 200 mm (7.9 in.) red grid was placed parallel to the track on one side of the test pole.

After the test, the length of the destroyed zone was measured, together with the wall thickness of the pole at ground level. Also, the deformation of the front end of the cars was recorded.

THE TEST POLES

The poles were spun cast by Genstar Structures, Ltd. of Calgary, Alberta. Standard forms were used and standard manufacturing procedures were followed, except that the concrete mix design was guided by the results of Ref. 1.

While the position of the prestressing wires could be controlled very well by applying a small prestressing force before wrapping around the continuous spirals, the outside concrete cover to the bars in the reinforced poles was not exactly 25 mm (1 in.) as planned; variations of concrete cover between 19 and 31 mm (0.75 and 1.2 in.) were observed on the broken poles. This difference, however, would not have affected the results significantly.

The poles were spun at 100 revolutions per minute for 3 minutes, then another 7 minutes at 300 revolutions per minute. Thereafter, the poles were heated in the form to approximately 80°C (180°F) for about 10 hours before release of the prestressing force and demolding of the pole.

The concrete mix was designed such that the segregation of the constituent materials was minimized. This was achieved by a relatively high aggregate content and a lower than usual sand content as is evident from Table 2.

The target strength was 40 MPa (5800 psi) at 28 days. With each pole, six control cylinders were produced and stored initially under the same environmental conditions as the poles. The average value of the strength tests is given in Table 3.

The 7 mm (0.28 in.) diameter prestressing steel was cold drawn wire with a nominal tensile strength of 1600 MPa (232 ksi). Three laboratory tests showed an average strength of 1690 MPa (245 ksi). The modulus of elasticity was 202 GPa (29,300 ksi).

The tests on the 12.7 mm (½ in.) reinforcing bars produced a yield strength of 547 MPa (79 ksi) and a tensile strength of 878 MPa (127 ksi). The 9.5 mm (0.37 in.) bars were not tested.

The prestressing wires were stressed to 1120 MPa (162 ksi) corresponding to 70 percent of the nominal tensile strength. The 10 gage wire used for the spirals had a yield strength of 550 MPa (80 ksi).

DESCRIPTION OF TESTS

In this section brief descriptions are given of the tests for Poles 1 through 11.

Test 1

In this test, the test vehicle collided with the prestressed concrete pole at a speed of 59.8 km/hr (37 miles per hr). Upon impact,

Table 3. Summary of test results.

Test No.	Concrete strength MPa	Impact speed km/hr	Deformation of front bumper m	Displacement of concrete pad m	Length of shattered zone m	Theoretical deceleration	Remarks
1	39.8	59.8	0.44	0.156, Pad destroyed	1.28	7.4 g	
2	46.6	50.4	0.42	0.060	1.22	5.9 g	
3	41.8	39.5	0.32	0.025, Pad destroyed	1.40	3.4 g	
4	38.7	33.0	0.37	0.040	0.78	3.5 g	
5	41.4	39.6	0.37	0.120, Pad destroyed	-	12.6 g	Break at midheight
6	41.4	40.2	0.26	*	1.24	4.3 g	
7	40.3	42.7	0.30	*	2.24	2.8 g	
8	43.8	40.6	0.30	*	1.60	3.4 g	
9	44.4	36.5	0.41	*	-	12.8 g	Did not break, but badly damaged
10	34.8	39.0	0.37	*	0.53	6.6 g	
11	37.3	40.1	0.30	*	0.84	5.5 g	

*No displacement of pad (pad frozen to ground).

Note: 1 ft = 0.305 m; 1 ksi = 6.895 MPa; 1 mile = 1.6 km.

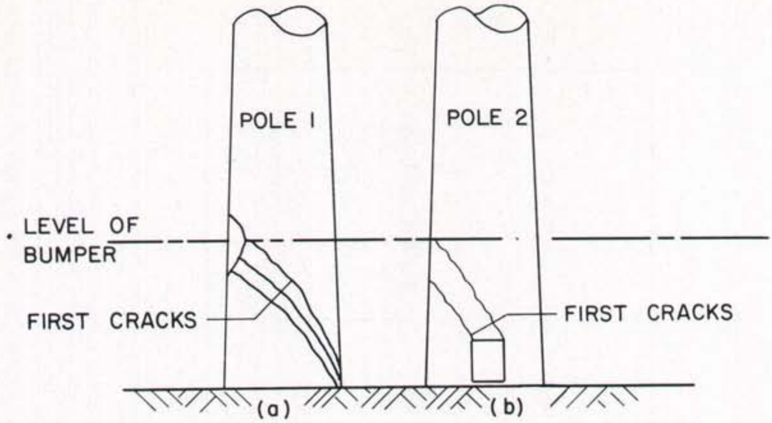

Fig. 7. Failure pattern of Poles 1 and 2 at beginning of destruction of pole.

first, the soft parts of the car, namely, the bumper, the grille and the radiator collapsed, resulting in a deformation of the car of approximately 450 mm (17.7 in.) Only after the motor block hit the pole did the destruction of the pole begin.

In the zone at the bumper level, first a number of diagonal cracks formed (Fig. 7a) and then the concrete disintegrated into many small pieces and the pole, still in a vertical position, was moved horizontally approximately 1.50 m (4.9 ft) with one layer of the pole after another being destroyed by the still moving vehicle.

At the instant the car came to a halt, the pole was falling away from the car (Fig. 8a) and broke at three points upon hitting the ground. The length of the shattered zone (Fig. 8b) was measured after the test to be 1.28 m (4.2 ft). The impact resulted also in the destruction of the concrete pad and measurements (as far as they were possible) indicated that the pad together with the pole was moved forward approximately 150 mm (5.9 in.).

The total movement of the car that occurred from the instant of first impact until it came to a complete halt was measured to be about 2.00 m (6.6 ft). Assuming constant deceleration, this results in a theoretical value of 69.0 m/sec (226 ft per sec) = 7.4 g.

After this first test, it was felt that an impact speed of about 60 km/hr (37 miles per hr) was excessive and therefore the speed in the second test was reduced.

A summary of all test data is presented in Table 3.

Pole 2

Pole 2 was similar to Pole 1 except that it had a small opening [100 mm wide × 180 mm high (3.9 × 7.1 in.)] at ground level. The test vehicle reached a maximum speed of 50.4 km/hr (31 miles per hr) at impact. Again, the softer metal parts of the car collapsed and wrapped around the pole before the pole showed any sign of destruction. Upon impact of the engine block, two inclined shear cracks starting from the corners of the blockout were first visible (Fig. 7b).

Thereafter, the concrete disintegrated in the impact zone and the pole was pushed horizontally about 1.2 m (3.9 ft) before the vehicle came to a complete stop. Then the pole fell forward and broke in two pieces when it hit the ground.

Pole 3

For this test, the vehicle speed was further reduced by releasing the test vehicle from a level 6.5 m (21.3 ft) above the bottom level to reach a speed of 39.5 km/hr (24.5 miles per hr).

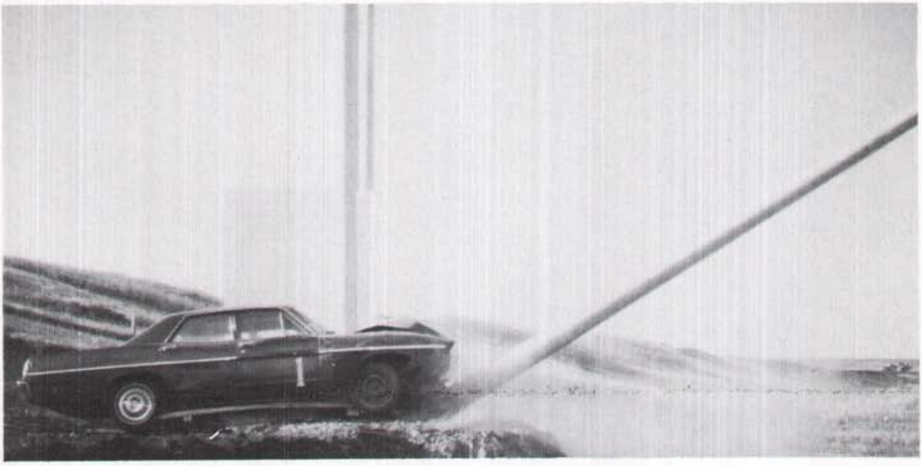

Fig. 8a. Test Pole 1 falling away from car.

Fig. 8b. Destroyed Pole 1 after test.

Because of the reduced car speed and the experience gained from the films of the first two tests, a clear picture of what happens, step by step, after the car hits the pole could be observed from the high and medium speed films.

First, three horizontal cracks appeared at the level of the bumper and simultaneously, a shear crack formed as shown in Fig. 9a. Subsequently, a shear failure occurred in the bottom zone (Fig. 9b).

The sequence of events is depicted in Figs. 10(a) to (f). As a convenient reference, the initial position of the pole centerline is indicated by a broken line. Steps 1 to 6 are described as follows:

1. The bumper of the car is hitting the pole and the first cracks form.

2. The first layer of the pole at ground level is sheared off [horizontal movement

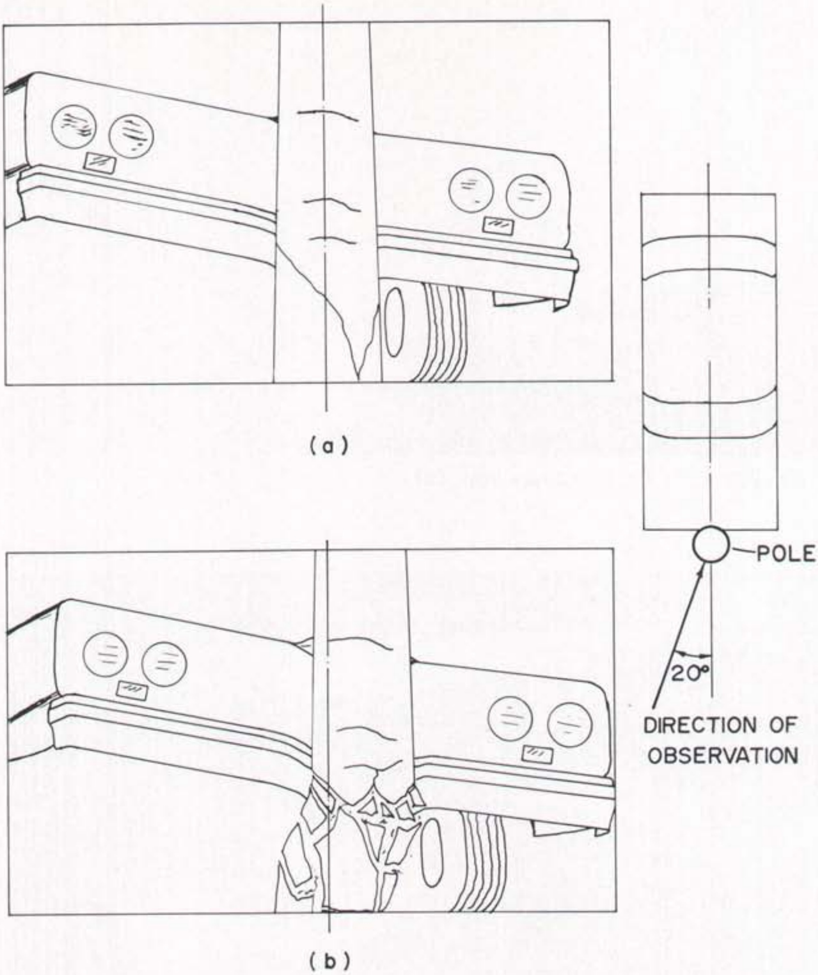

Fig. 9. First cracks (a) and shear failure (b) of Pole 3.

about 0.15 m (0.5 ft)].

3. A second layer of the pole is being sheared off in the plane of one of the initial flexural cracks. Each layer is destroyed by the reinforcement which cuts the concrete to pieces [horizontal movement 0.55 m (1.8 ft)].

4. Another layer of concrete is being destroyed [horizontal movement 0.75 m (2.5 ft)]. The pole leans towards the car.

5. Another layer of concrete has disintegrated and the pole is now horizontally displaced by 1.15 m (3.8 ft). The pole is leaning more towards the car.

6. The car has come to a complete halt after the pole has been moved horizontally by about 1.45 m (4.6 ft). The pole is now in near vertical position again (and subsequently falls away from the car).

After the test it was observed that none of the prestressing wires or reinforcing bars were broken and they were well anchored in the undamaged part of the pole below ground level.

This sequence of events is quite typical of those tests in which the poles collapsed

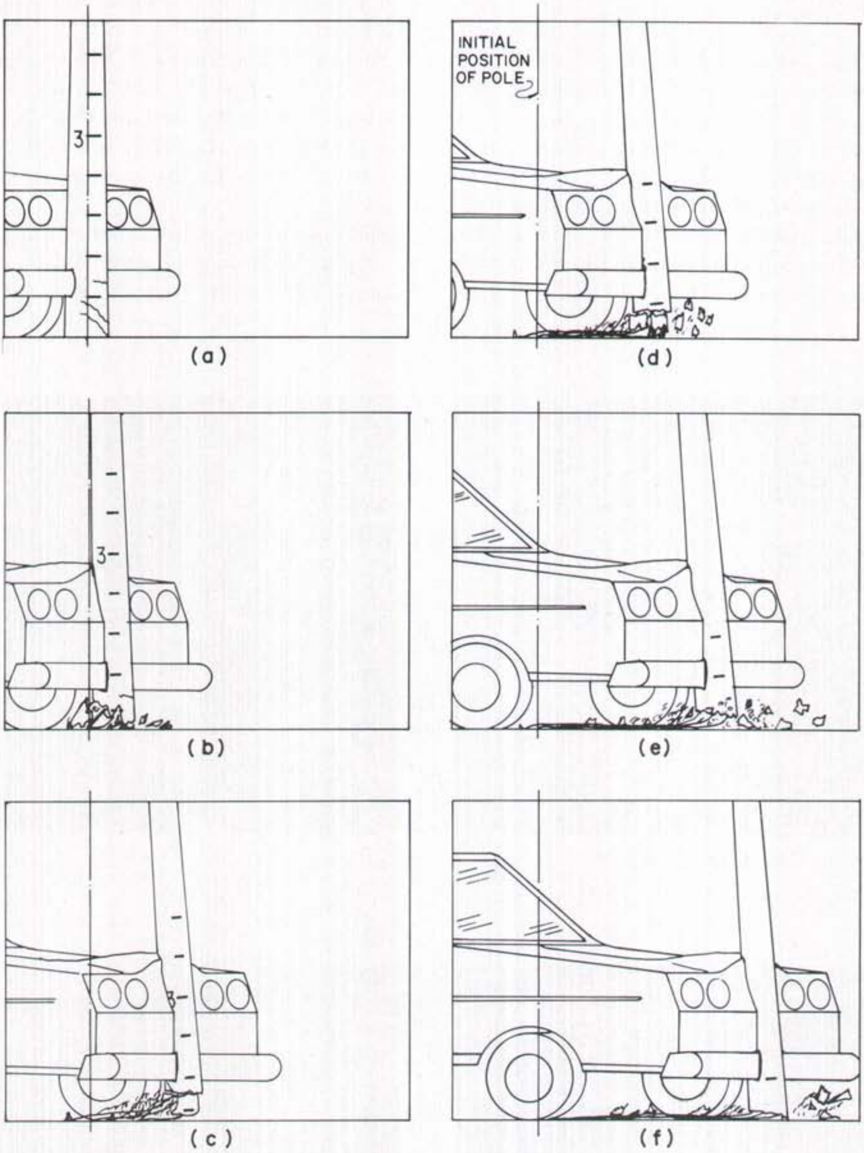

Fig. 10. Sequence of failure of Pole 3.

upon impact. It is apparent from Figs. 9b and 10b that the cause of the initial failure of the pole was shear which is indicated by the diagonal crack which formed in the bottom zone.

A photograph of the pole after testing is shown in Fig. 11.

Test 4

Pole 4 was reinforced with twelve 12.7 mm (½ in.) bars and had a wall thickness of 64 mm (2½ in.). The vehicle was released at a level 4.5 m (14.8 ft), resulting in the smallest test speed of 33 km/hr (21 miles per hr). The failure is similar to Test 3.

Test 5

This pole was reinforced with eight 7 mm (¼ in.) wires and eight 9.5 mm (⅜ in.) bars and the wall thickness was 68 mm (2.7 in.). The test vehicle reached an impact speed of 39.6 km/hr (25 miles per hr).

This pole did not break at the level of the impact zone but at a level 4.75 m (15.6 ft) above ground. The pole showed severe cracking over a height of 1.50 m (4.9 ft) and surface damage at the level of the car bumper (see Fig. 13).

The cracks shown in Fig. 13 were traced with a black felt pen to make them more visible. It must be assumed that these types of cracks are those which form first in all the tests but are not visible from a distance when filmed.

The fact that this pole did not collapse at the impact zone may be attributed to the following two factors: First, the wall thick-

Fig. 11. Pole 3 after the test.

Fig. 12. Pole 4 after the test.

ness of this pole was 68 mm (2.7 in.) which is slightly more than that of the previous test poles, and second, the concrete pad, which at the time of the test was only 48 hours old, split in three parts and allowed the pole to move 120 mm (4.7 in.) at ground level.

The breaking point, at a level 4.75 m (15.6 ft) above ground, coincides with the end of the 9.5 mm (3/8 in.) bars. The upper part of the pole fell away from the car and the top of the pole just reached the ground level after the break.

Test 6

Pole 6 was almost identical to Pole 5. The only difference was the wall thickness, 64 mm (2.5 in.) compared to 68 mm (2.7 in.). The test conditions were also similar in that a similar car hit the pole at approximately the same speed [40.2 km/hr (25 miles per hr)]. This pole, however, collapsed in the bottom zone in the previously described manner over a length of 1.24 m (4.1 ft) (see Fig. 14). It must be assumed that the smaller wall thickness and the rigid support at the level of the concrete pad (which was frozen to the ground) were responsible for the difference in behavior.

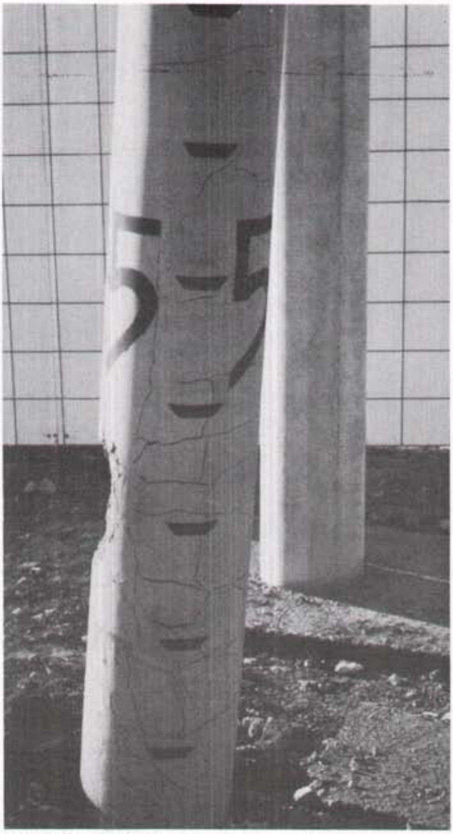

Fig. 13. Pole 5 after the test.

Fig. 14. Pole 6 after the test.

Test 7

The poles for Tests 7 and 8 had both less reinforcement and a smaller wall thickness [51 mm (2 in.)] than the previously described poles. Pole 7 was reinforced with eight 12.7 mm (½ in.) reinforcing bars and had a 100 mm (3.9 in.) spiral pitch.

This pole showed visible cracking before the test along its length which resulted from handling and shipping the pole.

The impact speed was 42.7 km/hr (26 miles per hr).

This pole was the most severely damaged of all the test poles in that it disintegrated over a length of 2.24 m (7.3 ft) in the way described in the sequence of Fig. 10. The concrete pad did not move.

Because of the substantial distance which the car was overriding the pole, the deceleration was only 27.7 m/sec (90.8 ft) = 2.8 g, the second lowest value recorded.

Test 8

This prestressed pole was destroyed in the same manner as shown in Fig. 10. The test data are given in Table 3.

Test 9

This pole was prestressed with twelve 7 mm (¼ in.) wires and the impact zone was provided with a closely spaced spiral. The wall thickness was 65 mm (2.6 in.) and the concrete strength had reached 44.4 MPa (6435 psi) at 28 days.

On impact the test vehicle was moving at a speed of 36.5 km/hr (23 miles per hr).

This pole was the second one which did not break. The bottom zone between the level of the bumper and the ground was, however, severely damaged as shown in Fig. 15.

Note that the shell outside the closely spaced spirals spalled off and shear cracks similar to those described in Tests 1 and 3 were evident.

Although the pole did not fall it was easily pulled down because of the severe damage it suffered upon impact. It appears that two factors have contributed to preventing collapse of this pole: first, the closely spaced spirals, which provide an effective type of shear reinforcement and, second, the slightly slower vehicle impact velocity.

Fig. 15. Pole 9 after the test.

Test 10

The pole for this test was the second one with closely spaced spirals in the impact zone, but it was prestressed by only eight 7 mm (¼ in.) wires. In addition, four 12.7 mm (½ in.) deformed bars were provided. The wall thickness at ground level was 63 mm (2.5 in.) and the concrete strength had reached 34.8 MPa (5043 psi), the lowest of all the tests.

The test vehicle reached a maximum speed of 39.0 km/h4 (24 miles per hr).

Upon impact, only the zone between the level of the bumper and the ground broke and consequently the horizontal movement of the pole was relatively small [about 0.30 m (1 ft)]. Subsequently, the pole fell away from the car.

It is apparent that the presence of the closely spaced spirals confined the destruction of the pole to a relatively small zone and for this reason, the vehicle came to a halt within a relatively short distance resulting in a relatively high deceleration of 65.2 m/sec (214 ft per sec) = 6.6 g. The failed pole is shown in Fig. 16.

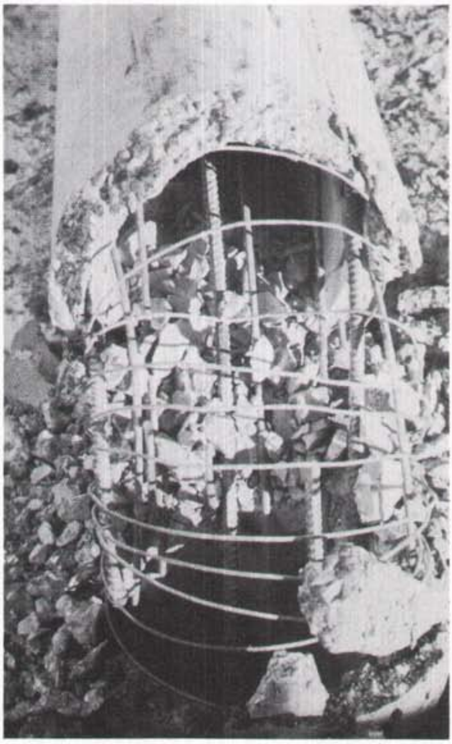

Fig. 16. Pole 10 after the test.

Fig. 17. Pole 11 after the test.

Test 11

This test failed in the way depicted in Fig. 10. The test data are summarized in Table 3.

SUMMARY OF TEST RESULTS

The type of failure recorded in all tests is a shearing type of failure which starts in the zone between the level of the bumper of the car and the ground level.

Realizing that it is shear that originates the failure, all the results fit very well into the present frame of knowledge regarding shear failure, namely:

1. Closely spaced shear reinforcement (spirals) increases the shear resistance significantly (see Tests 9 and 10).

2. Prestressed concrete poles (similar to other prestressed members) exhibit higher shear strengths than comparable reinforced concrete members.

3. The wall thickness plays a significant role with regard to the shear resistance.

4. The amount of flexural reinforcement has an influence on the shear strength in that a larger amount of reinforcement increases the strength.

In addition to the shear strength of the pole, the type of bedding of the pole plays a role with regard to the impact resistance. Rigidly supported poles seem more likely to break than those in a yielding support condition [in this case as expressed in terms of the movement of the concrete pad (refer to Test 5)].

EVALUATION OF TEST RESULTS

In Test 9 shear failure of the critical zone had developed as a result of the vehicle impact but the pole did not collapse. This test is now used to compare the force generated at the instant of the impact with the shear resistance of the pole.

According to the information provided, the vehicle had a mass of approximately 1500 kg (3.3 kips) and an average deceleration of 12.8 g. The resulting force is:

$$F = ma = (1500\text{ kg}) \times (12.8 \times 9.8\text{ m/sec}^2)$$
$$= 188{,}000\text{ N} = 188\text{ kN (42 kips)}$$

This force is assumed to be equal to the shear force in the critical zone. Assuming a diagonal shear crack as shown in Fig. 18, corresponding to the crack pattern shown in Fig. 7a, the shear resistance according to the Collins-Mitchell approach (Ref. 2) is approximated by (omitting the ϕ factor):

$$V_v = A_v f_y\, d \tan\theta / s = A_v f_y\, a/s$$

where

A_v = cross-sectional area of spiral (two legs)

f_y = yield strength of spirals

a = distance between middle of bumper and ground level

s = spiral spacing

d = effective depth of member

θ = angle between diagonal crack and vertical

With $A_v = 2 \times 9.07 = 18.14\text{ mm}^2$ (0.028 in.^{2}), f_y = 550 MPa (80 ksi), a = 450 mm (17.7 in.) and s = 25 mm (1 in.), the shear resistance can be found:

$$V_v = 18.14 \times 550 \times 450/25$$
$$= 179{,}000\text{ N} = 179\text{ kN (40 kips)}$$

The calculated shear resistance, V_v, does not include the increase in yield strength due to the high strain rate developed in the spiral during impact. This strength increase should be included in a more detailed study.

The comparison of the shear force developed in the pole by the vehicle and the shear resistance calculated leads to the conclusion that the designer can control the failure of spun cast concrete poles, if the impact force is known. This force depends on such parameters as vehicle speed, vehicle mass and type of vehicle.

If the pole is to withstand the vehicle impact, the distance within which the vehicle decelerates corresponds to the plastic deformation of the front end of the car. For a normal passenger car this deformation may be assumed to be about 0.40 m (1.3 ft).

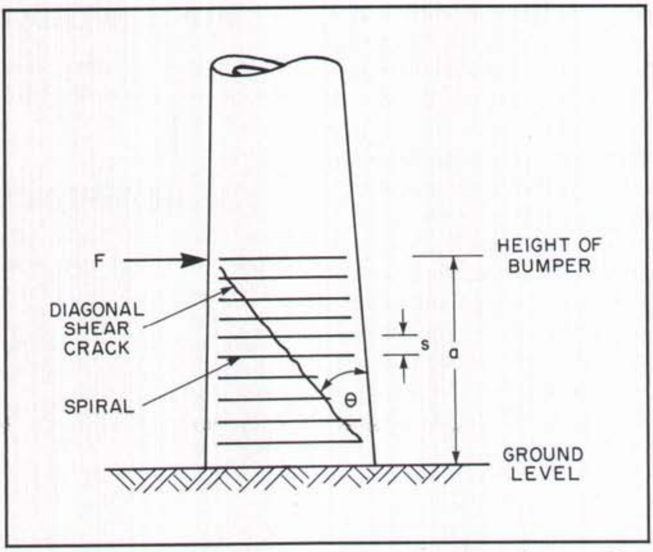

Fig. 18. Critical shear crack between bumper and ground level.

For a vehicular speed, v_o, the average deceleration is thus:

$$a\ (\text{m/sec}^2) = -\frac{1}{2}\frac{v_o^2}{0.4} = -1.25\ v_o^2$$

in which v_o is in m/sec.

If a collapsible pole is to be designed, the shear strength should be such that the maximum force during its service life can be resisted, but no extra shear strength should be provided by an excess of spirals in the impact zone.

DISCUSSION AND CONCLUSIONS

From the summary and evaluation of the test results, it is clear that the major criterion for the collapse of concrete poles is the shear strength. Thick walls and closely spaced spirals increase the impact resistance of concrete poles while thin walls containing only a nominal amount of spiral reinforcement lead to a low impact resistance.

It is the responsibility of building officials to establish criteria for impact resistance. Poles should be designed in such a way that they can resist the impact of a normal passenger car up to certain speed, say 30 km/hr (19 miles per hr), but at higher speeds the pole should break upon impact in order to save the lives of the passengers.

The question regarding the difference between reinforced and prestressed poles can be answered as follows: Both types of poles fail in the same way but it appears that prestressed poles are not destroyed to such an extent as reinforced poles if poles with the same wall thickness are compared. Also, prestressed concrete poles are normally produced with a smaller wall thickness than reinforced concrete poles of the same class. Consequently, it is likely that the prestressed pole will be destroyed to a larger extent than a nonprestressed pole designed to resist the same service loads.

In the discussions of the project with officials of the Canadian Electrical Association the possibility of producing break-away poles was mentioned. Such break-away poles are manufactured in steel.

From the way the poles collapse under vehicle impact, it is speculated that a break-away reinforced concrete pole could also be designed. The fact that the concrete is shattered in a zone of substantial length above the ground suggests that all the reinforcing bars could be spliced in this zone such that the part of the pole embedded in the ground is separated completely from the top part when hit by a fast moving vehicle. This idea, however, needs experimental verification.

The fact that in this test series, all poles which broke under the impact load fell away from the cars contradicts the results of the Ontario tests. It must be assumed that the smaller pole lengths and the smaller wall thicknesses [50 to 70 mm (2 to 2.8 in.) compared to more than 100 mm (3.9 in.)] and the resulting smaller inertia forces were the reasons for this.

ACKNOWLEDGMENT

The tests were carried out for the Canadian Electrical Association (CEA) under CEA Contract No. 76-25.

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NOTE: Discussion of this paper is invited. Please submit your comments to PCI Headquarters by September 1, 1986.