Development and Proving Tests of a Four-Rope Safety Fence

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Early two-rope safety fence needed to be installed on a hardened running surface to avoid undulations in the terrain causing vehicles to contact the fence at varying heights, with the consequent risk of ropes slipping over the car hood or being run over. A new design uses four ropes at two heights with the lower pair of ropes interwoven between the posts. Standard U.K. tests with a 1500-kg car impact at 113 km/hr (70 mph) and 20 degrees showed that this design met U.K. Department of Transport regulations. Further tests with a 750-kg car, at the same speed and angle, demonstrated that rope heights are no longer critical: the fence can now be installed on nonhardened surfaces, thereby reducing the unit costs of installation. Where on-road space for installation of safety fences is restricted, post separations may be reduced from 2.4 m to 1.0 m; this reduces the maximum penetration, under standard impact conditions, from 1.7 to 1.2 m. Analysis of impact severity using the theoretical head impact velocity concept showed the four-rope fence to have impact severity characteristics that match the current U.K. design of semiflexible fence. Other advantages of the fence are that the ropes do not require replacement or retensioning after vehicle impact and that damaged posts are easily removed from ground sockets and replaced with new posts.

Bridon PLC collaborated with the U.K. Transport and Road Research Laboratory in the 1960s on the development of a weak post-and-wire-rope safety fence for the containment of private cars. After a sequence of tests and prototype development, the final design consisted of two wire ropes, mounted above ground at approximately the same height, resting freely in a vertical slot cut into the top of steel posts. The weak-post concept avoided the then common problem of vehicles snagging on posts and spinning out of the fence in a hazardous manner.

The early tests had shown that the performance of the single-height wire rope safety fence was sensitive to rope height above the surrounding surface (*1*). If the ropes were too low they could be ridden over, and if too high they could slide over the hood of a small car. To overcome this, a restricted number of tests were completed with a two-height rope fence, but the tests proved unsuccessful. There was a tendency for the rear lower rope either to be trapped and carried to the ground by the posts or to break free too soon from its attachment to the post, fall to the ground, and then be run over by the vehicle.

The solution adopted at that time, and included in the U.K. Department of Transport (DTp) Technical Memorandum H9/73 (issued in 1973), was to retain the single-height, two-rope system in slotted posts and overcome the rope height problem by ensuring that the wire rope fence was always installed on a hardened running surface. This of course added to the cost, and in consequence, very little single-height wire rope fence was installed on U.K. highways. The longest length is in place on the M62 Motorway across the Pennine Mountains. This road is subject to snow drifting, and one of the benefits of the wire rope fence is that its narrow profile reduces the tendency for drifts to form.

Eventually, because of low demand caused by the high cost of preparing a hard running surface on which to mount the fence, the single-height rope fence was dropped from the U.K. DTp regulations. Nevertheless, the fence has had considerable use overseas, in Europe and the Middle East, where its ability to limit snow and sand drifting has been a most attractive feature.

DEVELOPMENT OF DOUBLE-HEIGHT, FOUR-ROPE SAFETY FENCE

Bridon PLC, in 1986, decided to reexamine the single-height design; its prime aim was to overcome the need to provide a hardened running surface and in so doing reduce the overall cost of the fence installation. To achieve this objective a series of 10 development tests were carried out at the Motor Industry Research Association (MIRA) in the United Kingdom.

First, a second pair of ropes was added (Figures 1 and 2). The distance between the upper and lower ropes and their heights above the ground were selected to permit vehicles to traverse an undulating surface and hit the fence without risk of a rope slipping over the hood. The posts may be held in socketed footings for easy replacement or repair, or soil-mounted posts can be used.

The use of this fence on U.K. roads has been approved by the U.K. DTp in Departmental Standard TD 32/89, which contains detailed drawings of the fence and components. The design has been submitted to and approved by the European Commission and member states of the European Economic Community; it is a patented product available worldwide.

Standard Impact Tests

The standard impact conditions for the testing of safety fences and barriers in the U.K. are quoted in British Standard BS6579 and in DTp Departmental Standard TD32/89. In the United Kingdom, for roads that have a maximum speed limit of 113 km/hr (70 mph), the fence should contain and safely redirect a 1500-kg, 113-km/hr vehicle impact at 20 degrees.

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In addition to the standard test, the U.K. DTp requested of the Bridon design that the maximum dynamic deflection of the fence be less than 2.0 m. Also, the vehicle exit trajectory had to meet the "box" criteria of BS6779, which state in part

> [I]f redirection takes place the vehicle shall be redirected so that no part of it crosses the line drawn parallel with and 2.13 metres, plus the width of the vehicle, from the face of the parapet, within a distance of 10 metres from the break point of vehicle contact with the parapet (fence). The test vehicle should neither turn on its side nor roll over the paved parapet test area.

Bridon Ropes Ltd (a subsidiary of Bridon PLC) was asked to meet all these requirements in the design of its vehicle safety barrier.

One of the main purposes of the tests was to demonstrate that the new four-rope design could perform successfully when mounted on an uneven surface.

The material specification for the running surface over the impact test area led to considerable discussion. On-road sites, where safety barriers are installed, have a wide range of surfaces—from grass, to aggregate, to hardened macadam—all with varying degrees of undulation and hardness. Repeatability of tests was a prime consideration. The solution adopted, in part, followed previous practice using a hardened running surface for the standard 1500-kg saloon car test; this was followed by a second test, with a 750-kg minicar. The smaller, lower profile of the 750-kg car would, to a reasonable degree, represent a standard vehicle that had either penetrated into a soft running surface or was traversing an undulating surface where a rope could slip over the hood when the car was at the lowest part of the undulation. This test would also explore the impact severity and vehicle trajectory response of the fence with a lightweight car.

Design of Four-Rope Safety Fence

Post Spacings and Rope Heights

Bridon Ropes Ltd considered that fence post spacings of 2.4 m would be needed to meet the 2.0-m maximum dynamic deflection criteria, requested by the DTp, when tested under standard impact conditions with the 1500-kg car.

It was foreseen that a stiffer fence would be required where the fence, in an on-road situation, was installed close to roadside features such as lamp columns and gantry signs. To meet this situation, tests were made on a fence with post spacing reduced from 2.4 m to 1.0 m.

All designs were dynamically tested by impact with driverless 1500-kg and 750-kg cars, at a target impact speed of 113 km/hr at 20 degrees.

In the final design, posts of z-shaped cross section were manufactured from 6-mm gauge steel having a yield strength of 335 N/mm². A short slot supported the two upper ropes at a height of 585 mm; the lower ropes were supported by small brackets each side of the z-posts at a height of 490 mm Figures 1 and 2). The posts were held in concrete sockets with sufficient clearance for easy removal and replacement of damaged posts.

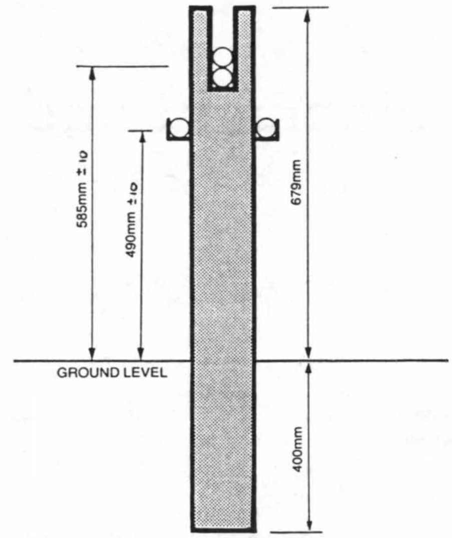


FIGURE 1 Z-section slotted post.

Preliminary Tests

A series of nine tests was carried out during 1987 and 1988; they were followed by two more tests in 1991 on a stiffer fence designed for lower deflection on impact.

In the first of these series, four ropes were placed in pairs in a deep single slot cut into the top of the post. The upper pair was at a height of 635 mm and the lower pair was at 400 mm. On impact by a 1500-kg vehicle, this design failed: the flanges of the slots fractured before the base of the posts started to bend. Without the retaining flanges the ropes were free to break free from the posts ahead of the test vehicle and fall to the ground, where they were subsequently run over. Although the vehicle was contained, this design was abandoned.

In the second 1500-kg car test, the static rope tensions were increased from 13 to 27 kN. Again the vehicle was contained but the lower ropes were run over. This test produced the unexpected result that the higher static rope tension had little influence on the dynamic fence deflection: it increased from 3.1 to 4.9 m.

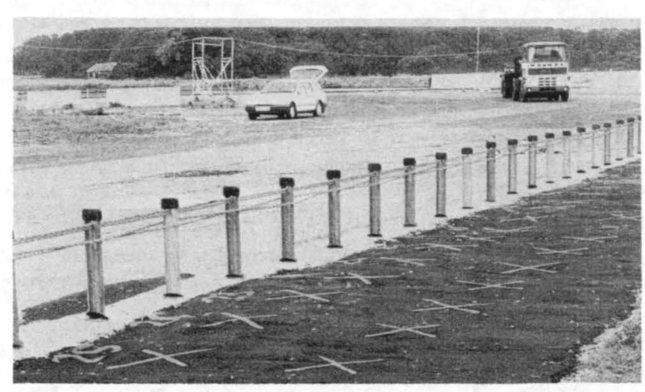


FIGURE 2 Four-rope safety fence.

The design adopted in all later tests used two ropes located in a shallow slot in the top of the posts, with two lower ropes placed on simple brackets fixed to each side (Figure 1).

In the third test, rope heights were again at 635 and 400 mm, with static tensions 31 and 13 kN in the upper and lower pairs of ropes. In addition, the lower pair was interwoven in a crisscross fashion between every second post. This in effect produced a simple mechanism that trapped the rope between posts and so maintained rope height ahead of the vehicle. The 1500-kg vehicle was contained and the penetration was reduced to 2.4 m, but one rope was run over.

In the fourth test the bending strength of the posts was increased by increasing the material thickness from 5 to 6 mm. The rope heights were 635 and 490 mm with static tensions of 31 kN (upper) and 27 kN (lower). The 1500-kg vehicle was safely contained and redirected in a maximum deflection of 1.8 m.

The fifth test was with a 750-kg car. Rope heights were increased by 50 mm to 685 and 490 mm; rope tensions were the same as the previous test. The maximum deflection was 1.1 m. The vehicle was contained and redirected but the upper ropes slipped over the bonnet. The vehicle path remained close to the fence and the car made second contact; as it came to rest it rolled onto its side, partly because of the impact damage to the front left-side wheel station.

The fifth test was repeated with the upper ropes lowered by 50 mm to 635 mm and the static rope tension reduced to 22 kN. The car was contained by both pairs of ropes, safely redirected, and made second contact with the fence about 60 m from the impact point. The vehicle did not roll over.

In the seventh test the lower pair of ropes were interwoven between every post (Figure 3), rather than every other post as in the previous tests. The purpose was to improve the retention of rope by trapping it against the posts. Together with this modification, the rope heights were reduced by 50 mm, making the new heights 585 and 490 mm. Clearly the lower rope heights made it possible for the cables to be run down. However, if the extra interweaving proved effective and the ropes maintained their heights during impact, the overall lower rope heights would certainly represent an improved configuration and be beneficial for the smaller car. Static tension in all ropes was 22 kN.

This test proved very successful. The configuration of rope heights (585 and 490 mm), post material thickness (6 mm), and static rope tension (22 kN) was retained in the proving tests of the four-rope safety fences with 2.4- and 1.0-m post spacings. The proving tests of the 2.4-m fence and the 1.0-m fence by impact with a 1500-kg car and a 750-kg car are described in detail in the next section.

PROVING TESTS OF FOUR-ROPE SAFETY FENCE

Rope Characteristics

Vehicle impact tests showed that static rope tensions between 13.3 and 26.7 kN (3,000 and 6,000 lb) had little effect on dynamic deflection of the fence. This result is beneficial in service, in that the fence deflection performance is not sensitive to variations in tension brought about by changes in ambient temperature. A static tension value of 22.25 kN (5,000 lb), set at 15°C, is specified for the final design. For a temperature range of −10 to 30°C the rope tension ranges from 36.0 to 14.0 kN.

The ropes are 19 mm in diameter, zinc-coated with a minimum breaking load of 173.6 kN (17.7 T) each. The rope is formed by twisting six wires around a king wire to form a strand; three strands are twisted together to form the rope. The maximum tension recorded in all of the tests was 22.6 kN, and maximum length between anchorages is 626.4 m. Intermediate anchorage overlaps have been successfully designed and tested but are not the subject of this report (*1,2*).

Throughout the series of tests, there was no need to replace or retension any of the ropes; at the end of the program the ropes were in a condition suitable for on-road use. All initial

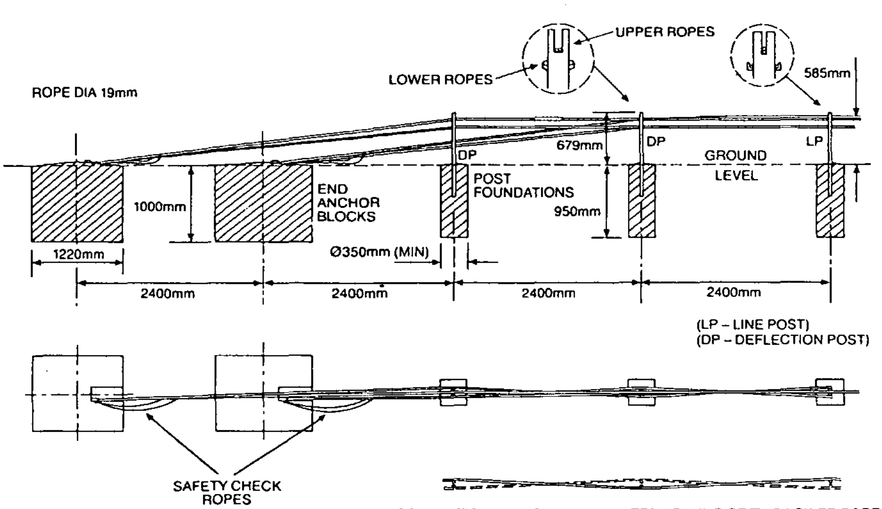


FIGURE 3 General arrangement of four-rope safety fence showing rope interwoven between very post.

impacts occurred at the same point along the fence. Ropes are prestressed (prestretched) before installation to remove all nonelastic stretch; this ensures that tension is maintained in the ropes after they are stretched under vehicle impact conditions.

Four-Rope Safety Fence with 2.4-m Post Spacings

Posts were spaced at 2.4-m intervals to span the impact area of 48 m. The length of rope between anchorages was 626.4 m; turnbuckles were adjusted to set the static tension in all four ropes at 22.24 kN. Rope heights were set at 585 and 490 mm. The lower pair of cables was interwoven at every post.

1500-kg Car Test

The standard weight (1500-kg) car test (Figure 4) at 113 km/hr (70 mph) impacted at an angle of 19 degrees, deflected the fence a maximum distance of 1.7 m, and it was safely redirected onto a departure path of 7 degrees to the line of the fence, with 0 yaw angle.

First contact was over a length of about 19 m. The driverless car then steered back, remained in contact with the fence for a further 19 m, and came to rest about 125 m from the first point of impact (Figure 4).

The main damage to the car was restricted to the area around the impact wheel station; the passenger compartment was undeformed, all four doors could be opened and closed, and all safety glass remained intact. The front left-side corner was pushed in about 300 mm. On the second impact, at about 60 m from impact point, the front left-side wheel station collapsed. The vehicle came to rest about 125 m from the impact point alongside, and just touching, the fence.

In the primary impact, nine posts were damaged over a length of 19.2 m; a similar length was damaged in the secondary impact.

The test complied with the requirements laid down by the U.K. DTp as well as the exit trajectory criteria stipulated in BS6779.

750-kg Car Test

The lightweight (750-kg) car test (Figure 5) is not a formal requirement of the U.K. DTp regulations for safety fences on highways; however, it was carried out, by request of the DTp, to observe whether the lighter car would either snag on the posts and spin out or be redirected after impact at a high angle, due to stored energy in the ropes being returned to it. Additionally, the test represented an impact on the fence of a lower profile car at a lower running height, a condition that could occur with a heavier vehicle on soft ground, both of which may result in the upper rope slipping over the hood.

The fence configuration was identical to the previous 1500-kg car test. The test speed and angle were 116 km/hr (72.1 mph) and 19 degrees. The maximum penetration into the fence was 1.2 m, and the damaged length was about 15 m. The car was safely redirected on an exit path of 7 degrees (center of gravity point) with the car at a yaw angle of about 1.5 degrees to the line of the fence.

On impact, the four wire ropes were forced together and made contact with the front left-hand corner of the car at headlamp height; there was no indication of a rope slipping over the hood. The front left-side wheel suspension damper was damaged, but the wheel remained attached to its upper and lower mountings. The occupant compartment was undeformed, all safety glass remained intact, and both doors could be opened and closed.

The maximum roll angle of 10 degrees occurred at 0.3 sec after impact; at this moment both left-side wheels were clear of the ground. As penetration decreased, the roll angle reduced to 0 degrees and the car left the fence in a stable condition. There was no indication of spinout.

Contact length was over a distance of about 15 m; seven posts were damaged and needed replacement.

The wire rope fence impact test with the 750-kg car successfully met the performance requirements of the DTp, and met the exit path criteria laid down in BS6779: Part 1. In addition, the fence met the running height conditions for soft ground, and the approved fence no longer required mounting on a hardened running surface.

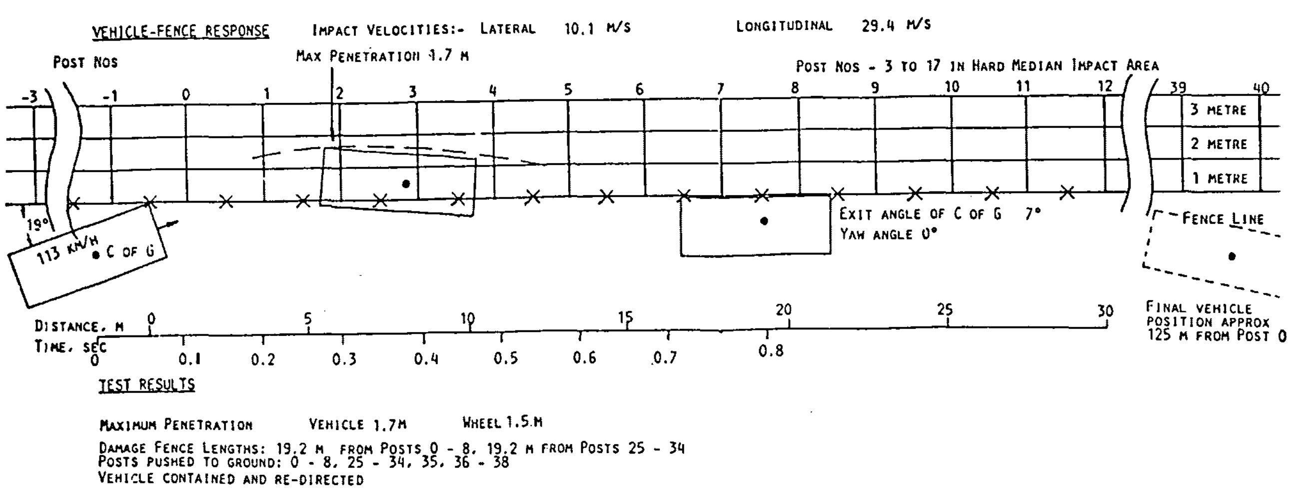
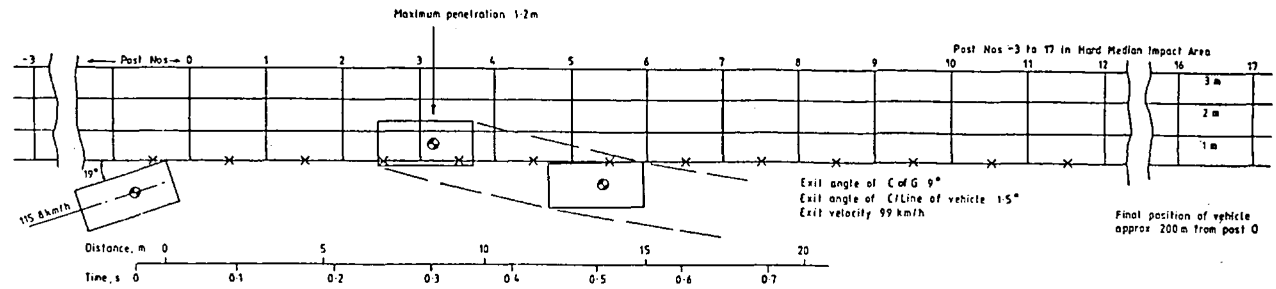


FIGURE 4 Summary of 1500-kg car test (2.4-m post spacings).

VEHICLE FENCE RESPONSE   Impact Velocity :   Lateral 10·5 m/s   Longitudinal 30·4 m/s



TEST RESULTS

Maximum Penetration : Vehicle 1·2 m   Wheel 1·2 m
Damage : Posts 0 to 4 pushed to ground.
Posts 5 & 6 bent 65° to vertical.
Remarks : Vehicle contained and redirected.

FIGURE 5 Summary of 750-kg car test (2.4-m post spacings).

Four-Rope Safety Fence with 1.0-m Post Spacings

The rope lengths, rope heights, and post cross-sectional dimensions for the fence with the 1.0-m post spacings were identical to those in the 1500-kg and 750-kg car tests, on the 2.4-m fence.

Over a 30-m length of fence, designated the impact area, z-posts were slotted into sockets 1.0 m apart. The remaining lengths of rope near the impact area were supported on posts placed 2.4 m apart. The overall length of the fence was 319 m; the rope static tension was set, by turnbuckles, to 26.5 kN.

1500-kg Car Test

The standard-weight (1500-kg) car impacted at 115.8 km/hr at an angle of 19 degrees (Figure 6). An anthropometric dummy representing a 50th-percentile man was installed in the passenger seat of the car. The exit speed was 90 km/hr at an angle of 8 degrees (Figure 6).

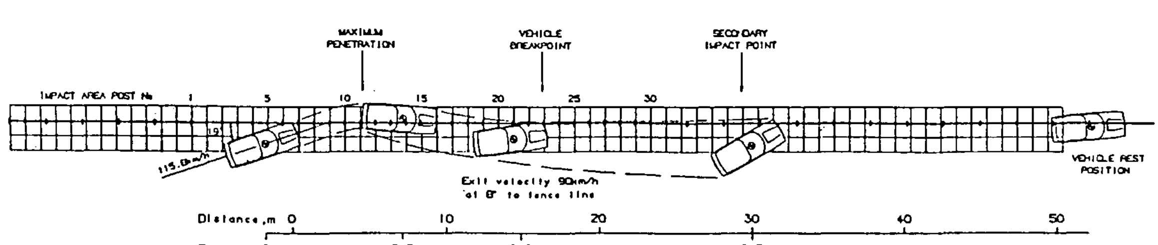
On impact the four ropes were forced together and formed a groove in the vehicle bodywork at headlamp height. At 0.24 sec after impact the car was parallel with the fence and had penetrated 1.1 m; the ropes pressed into the left-hand side body panels, and at this point the maximum deflection was 1.08 m. As the vehicle continued along the fence, the maximum penetration was recorded as 1.12 m where the ropes had cut into the rear left-hand side wheel arch.

The maximum penetrations and deflections are given in the following table:

Time (sec)	*Vehicle Penetration (m)*	*Rope Deflection (m)*
0.10	0.6	0.58
0.24	1.1	1.08
0.30	1.2 (maximum)	1.12
0.30	1.3 (loose hood)	1.12

During the impact 17 posts were damaged. After leaving the fence, at a shallow angle, the car made second contact

VEHICLE BARRIER RESPONSE   Impact velocities: Lateral: 10.5 m/s   Longitudinal: 30.4 m/s



	Time after impact, s	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
Vehicle acceleration, g from accelerometers Filter: 10Hz, 48dB/oct	Lateral, g	-2.1	-3.1	-3.5	-5.7	-5.9	-4.2	-1.7	-1.0	0.1	0.5	0.6	0.7
	Longitudinal, g	-3.3	-3.1	-2.7	-1.4	-1.9	-1.5	-2.3	-1.4	-1.3	-1.2	-1.0	-0.7
	Vertical, g	-0.1	0.1	0.1	-0.7	0.1	0.7	0.1	-0.3	-0.6	0	-0.2	-0.1
	Resultant, g	4.0	4.4	4.4	5.9	6.2	4.6	2.8	1.7	1.9	1.2	1.1	1.0
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	46	56	58	85	87	61	24	15	0	0	0	0
	Longitudinal, kN	37	31	30	16	31	26	34	20	27	17	14	12

MEAN DECELERATION of vehicle for duration of 0.58 s
Lateral: 2.3 g   Longitudinal: 1.9 g

REMARKS The vehicle was contained and redirected by the Wire Rope Safety Fence

FIGURE 6 Summary of 1500-kg car test (1.0-m post spacings).

about 13 m from the break point. Another 10 posts (2.4-m spacings) were knocked down, and the vehicle came to rest 52 m from the initial contact point.

The front left-hand corner of the vehicle had been pushed in about 300 mm; superficial rope marks could be seen along the left-hand side of the car at headlamp height. The front left-hand side suspension was badly damaged; the wheel had been pushed forward and had twisted 90 degrees from its true position. There was no visual damage to the occupant area and all four doors could be opened after the vehicle was moved from alongside the fence. Damage is shown in Figure 7. Analysis showed that the test had complied with DTp requirements and also had met the exit path requirement stipulated in BS6779. The results of the analysis are shown in Figure 6.

The effect of reducing the post spacings from 2.4 to 1.0 m reduced the deflection of the wire rope fence from 1.7 to 1.12 m.

FIGURE 7 Final position of 1500-kg car (1.0-m post spacings).

750-kg Car Test

A 750-kg car test (Figure 8), as mentioned earlier, is not a requirement of the DTp regulations; however, there was a possibility that the closer post spacing of 1.0 m could cause wheel snagging and induce a small car to spin out. Also there was the possibility that the lower profile of the smaller car, compared with the 1500-kg car, could permit the ropes to slip over the hood. In addition, the smaller car could represent a larger vehicle running on soft ground, whose height, relative to the fence, was lowered by the wheels penetrating the running surface. In addition, the test with a light vehicle would give an indication of the severity of impact.

Impact speed was 113.4 km/hr at an angle of 19 degrees; the vehicle left the fence at a speed of 90 km/hr at an angle of 1 degree to the line of the fence, with the rear of the vehicle farthest from the fence.

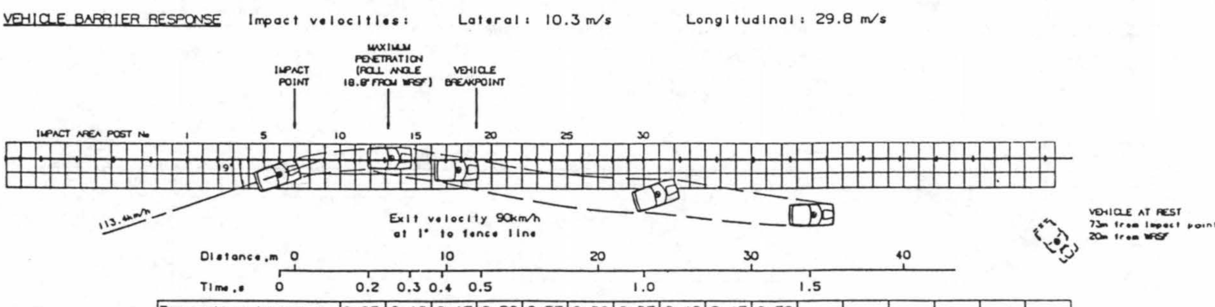
During impact, there was no indication of a rope slipping over the hood. As before, with the 1500-kg car, the four ropes formed a shallow groove in the front left side at headlamp height. At 0.08 sec after impact the windshield shattered. At 0.26 sec the maximum penetration was 0.86 m and the maximum rope deflection was 0.84 m; at this time both left-side wheels were clear of the ground (Figure 9). The car began to move out of the fence while remaining fairly parallel; there was no indication of spinout. The rear of the car yawed slightly away from the line of the fence, and it came to rest 73 m from impact point and about 20 m in front of the fence.

About seven posts were run down and another six posts were bent and needed replacement.

The front left-side quarter was crushed inward about 200 mm. The left-side front suspension unit was detached from the stub axle, and the wheel was trapped in the crushed body panels at 90 degrees to its normal running axis. The passenger door could be opened from the inside with normal manual force but could not be opened from the outside.

The test successfully passed the DTp requirements, and the exit angle complied with BS6779. Also, all ropes remained in contact with the side of the car; none slipped over the hood.

VEHICLE BARRIER RESPONSE Impact velocities: Lateral: 10.3 m/s Longitudinal: 29.8 m/s



	Time after impact, s	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50						
Vehicle acceleration, g from accelerometers Filter: 10Hz, 48dB/oct	Lateral, g	-3.3	-4.7	-3.8	-3.1	-2.2	-1.1	-0.4	0.4	0.8	0.7						
	Longitudinal, g	-5.8	-4.4	-3.1	-2.1	-1.6	-0.6	-0.7	-0.6	-1.0	-0.7						
	Vertical, g	0	-1.0	1.2	2.4	2.3	0	-0.8	-0.5	-0.7	-0.8						
	Resultant, g	6.7	6.5	5.1	4.5	3.6	1.3	1.1	0.9	1.4	1.2						
Vehicle forces, derived from accel. relative to undeflected barrier	Lateral, kN	36	42	32	25	17	8	3	0	0	0						
	Longitudinal, kN	33	21	16	12	10	4	5	4	7	6						

MEAN DECELERATION of vehicle for duration of 0.47 s
Lateral: 2.0 g Longitudinal: 2.2 g

REMARKS The vehicle was contained and redirected by the Wire Rope Safety Fence

FIGURE 8 Summary of 750-kg car test (1.0-m post spacings).

FIGURE 9 750-kg car during impact (1.0-m post spacings).

The test demonstrated that the four-rope fence met the running height conditions for soft ground.

VEHICLE IMPACT SEVERITY

The severity of impact was estimated using the value of the theoretical head impact velocity (THIV). The THIV value estimates the impact velocity with which a freely moving object, representing an occupant's head, would hit a surface in its path inside the vehicle compartment.

Figure 10 compares THIV values for standard tests with a 1500-kg car and a 750-kg car at 113 km/hr, in collision with a concrete barrier, a steel tensioned corrugated beam (TCB) fence and the wire rope fence with 2.4- and 1.0-m post spacings.

In terms of the THIV values, the 2.4-m wire rope fence is no worse than the TCB fence at about 4 m/sec for the 1500-kg car and about 5.5 m/sec for the 750-kg car. A comparable THIV value for impact into a vertical concrete barrier (VCB) is about 7 m/sec for the standard 1500-kg car.

The THIV value increased from 4 m/sec for the wire rope fence with 2.4-m post spacings to 5.6 m/sec for the 1500-kg car impact into the 1.0-m fence.

The THIV value for the 750-kg car impact into the 1.0-m fence was 6.4 m/sec compared with 8.4 m/sec for its impact into a VCB.

The CEN standard on road restraint systems is likely to recommend that THIV values should not exceed 9 m/sec for Impact Severity Level A and 12 m/sec for Level B. The impact tests demonstrated that both the 2.4- and 1.0-m wire rope fences met the proposed CEN standard for impact severity with THIV values less than the lower recommended value of Level A.

The head injury criterion (HIC) for the passenger dummy was very low at 56, in the 1500-kg car test on the fence with 1.0-m post spacings; the limiting injury value defined in FMVSS in 1,000.

CONCLUSIONS

- The Bridon Ropes wire rope safety fence, with post spacings at 2.4 and 1.0 m, met the impact performance requirements laid down by the U.K. DTp for highway safety fences. The fences also complied with the vehicle trajectory after impact given in BS6779, Part 1.
- The 1500-kg vehicle was safely contained and redirected, after a standard 113-km/hr impact into the 2.4-m four-rope fence. The vehicle departure path was 7 degrees to the line of the fence, and the maximum penetration was 1.7 m.

This test was repeated for the 1.0-m fence; the maximum vehicle penetration was 1.2 m. The reduction in penetration of 0.5 m permits the wire rope fence to be considered for use where site space is restricted. For example, reduced post spac-

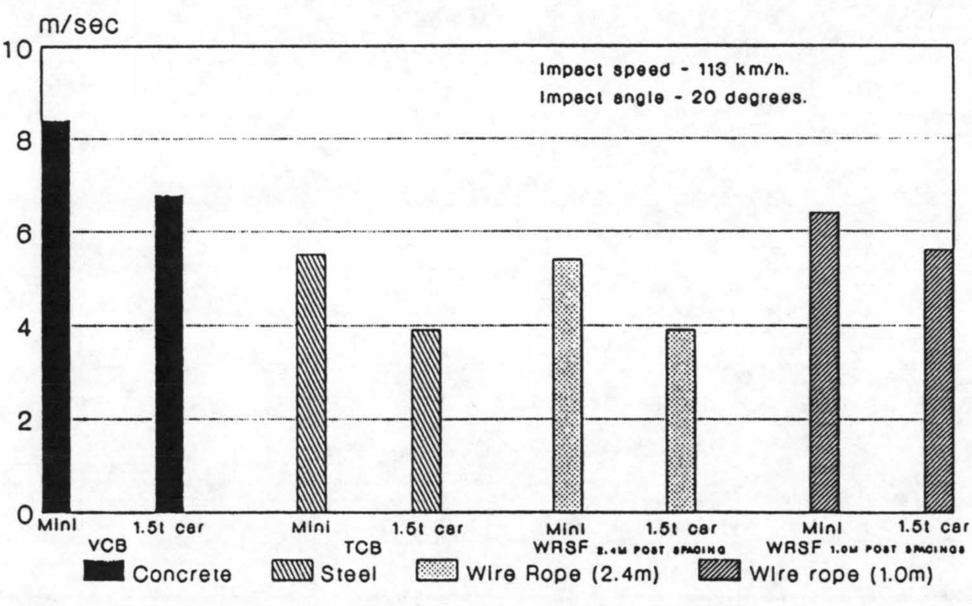


FIGURE 10 Theoretical head impact velocity comparison (mini-750-kg car).

ing would be used to restrict fence deflection where lighting columns were placed close to the safety fence.

- Additional tests with 750-kg car impacts at target speeds of 113 km/hr at 20 degrees also successfully met the U.K. DTp and BS6779, Part 1 requirements. The maximum penetrations were 1.2 m for the 2.4-m fence and 0.86 m for the 1.0-m fence. In addition, these tests demonstrated that the 750-kg car, which has a lower front profile than the 1500-kg car, did not penetrate beneath the fence ropes.
- The maximum tension measured in all vehicle impact tests was 22.6 kN; the breaking load of a single rope is 173.6 kN. The same ropes were used for all the tests; none of the ropes received damage that would require rope replacement at a roadside installation. The fence was quickly repaired after each test by manually extracting the damaged posts from the concrete sockets and replacing them with new ones. In none of the whole series of tests was a post pulled from its socket during vehicle impact. After each test the wire ropes were lifted into place without needing retensioning or mechanical power equipment.
- Vehicle impact severity for the standard 1500-kg car test, using the THIV measure, was 4 m/sec for the 2.4-m post spacing four-rope fence; this is similar to that of the TCB fence for the standard 1500-kg car test. The THIV value increased from 4 to 5.6 m/sec for the 1.0-m fence.

The respective values for the 750-kg car tests on the 2.4- and 1.0-m fences were 5.5 and 6.4 m/sec.

Both the 2.4- and the 1.0-m fences met the THIV level for impact severity given in the draft CEN standard, with THIV values considerably less than the recommended 9 m/sec.

The HIC value of 56 recorded for the standard 1500-kg car test and the 1.0-m post spacing fence was considerably lower than the injury threshold of 1,000 units quoted by FMVSS.

- The U.S. performance requirements (given in *NCHRP Report 230*) (*2*) for safety barriers are under revision. The 750-kg and 1500-kg U.K. car tests are likely to meet the Report 230 requirement for impact by an 1,800-lb car at 15 degrees and 60 mph. The U.K. 1500-kg car test at 20 degrees and 70 mph has an energy level, with reference to the component velocity normal to the fence, that is about 50 percent lower than the U.S. 4,500-lb car test at 25 degrees and 60 mph. However, it is likely that the wire rope safety fence described in this report will be tested according to *NCHRP Report 350* (*3*), the revised version of Report 230.

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