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13 June 2002

Mr. G. Sharp,  
BRIFEN Ltd.,  
AKAMSARA,  
Ratcher way,  
Crown Farm Industrial Park,  
Mansfield,  
NG19 0SF.

Dear Graham,

### **Simulated Fence Performance**

You asked us to see if our simulation software could say anything useful about two fence designs; a design developed and tested in Sweden, and a design for verges. The pages attached to this letter give some details of our findings. Please note that they are simulation results from the Brifsim2 software developed here in association with Bridon Ropes (and with the Brifen team when you were with Bridon). The software is validated against data from about 15 full impact tests involving a range of vehicles.

I am indebted to Gavin Beattie for performing the simulations and taking part in discussions with the Swedish team when you and they visited us here. Gavin is one of our final year Masters students, who chose safety fence development for his final year project.

I draw your attention particularly to the first page overleaf, which is a summary of our findings. I have tried to emphasise the practical testing consequences that we are able to make from the results of the simulations that Gavin performed. The pages that follow set out the details upon which our findings are based.

If you need any further information or clarification on this, please get in touch with me.

Yours Sincerely,

Ian Howard

# Conclusions

## Swedish Comparative Fence Testing

- A simulation of the impact test of the Brifen woven fence carried out in Sweden predicted a maximum deflection of 1.27m, just within the W4 rating. A simulation of the test of the Swedish fence design predicted a deflection of 1.74m. This is much greater than the 1.2m reported by the engineers at the Swedish testing ground. An un-woven Brifen fence of the same length as the woven one had a simulated penetration of 1.23m. The fact that this was smaller than that for the woven design provoked a further investigation into the relation between maximum deflection and fence length.
- Increasing the fence length increases the maximum deflection inexorably for un-woven fence designs. However, all woven designs had an upper limit to deflection. This occurs between 200m and 400m fence length depending on post spacing (between 2.4m and 3.2m).
- Testing of woven fences that are shorter than 200m for 2.8m post spacing and 300m for 3.2m post spacing under-estimates the penetration of vehicles into roadway fences that are strung at longer lengths than the test comparator.
- For un-woven fences, without a fence-length model, there is no safe fence testing length that is shorter than the expected full roadway fence length.
- The deflection reduces with post spacing for all fence designs analysed.

## Verge Fences

Simulations of a fence designed to protect vehicles penetrating the verge of roadways with dangerous edges produce the following predictions for the maximum deflections.

Vehicle Mass	maximum deflection
900 kg	1.14 m
1500 kg	1.58 m

These figure, although large compared with the limits set for penetration of roadway medians, are quite reasonable for this application, where vehicle containment is the only criterion of acceptance.

# 1. Swedish Fence Design

## Introduction

Swedish testing standards rate the performance of a Wire Rope Safety Fence (WRSF) in terms of maximum deflection during impact of a 1500kg test vehicle, for a 20° nominal impact angle at 70mph nominal impact velocity. The rating a fence system receives depends upon the criteria set out in Table 1.

Rating	Maximum Deflection
N2 W5	< 1.7m
N2 W4	< 1.3m

*Table 1: Swedish Performance Criteria*

Swedish testing of a Brifen three-rope wire fence had obtained a deflection of 1.4m, resulting in a W5 rating. A Swedish similar system that used the same number and type of ropes but without the interweaving between posts unique to Brifen had obtained a deflection of 1.2m and hence a W4 rating.

These tests are unusual, by Brifen testing standards, which use fence lengths of several hundred metres in order to represent typical roadway scenarios effectively. The fence lengths tested were around 100 metres, with the Swedish design being somewhat less, about 70 metres. For an un-woven fence, the fence length has a significant influence on fence performance, particularly when it is short. Simulation offers a way of comparing these different designs in a like-for-like basis.

## Primary Fence Simulation

We simulated three fence designs: the Brifen three-rope system with and without rope weaving, and the Swedish non-woven system. The latter differed from the Brifen system mainly in the posts. These were smaller than the Brifen posts, made from 3mm gauge steel rather than the Brifen 6mm, and had an I-section rather than the Z-form used in Brifen. Table 2 shows the main parameters used in these simulations.

Table 3 compares the predicted maximum deflections. The Brifen products out-perform the Swedish design substantially. What is particularly puzzling is that the simulated Swedish penetration is 40% bigger than the test data. This discrepancy cannot be explained from the simulation results available.

<b>Parameter</b>	<b>Value</b>
Vehicle Mass	1500kg
Impact Velocity	70mph
Angle of Impact	20°
Test Length	100.8m
Post Spacing	3.2m

*Table 2: Brifsim2 Input Parameters*

Furthermore, both Brifen products achieve a W4 rating in simulations of a 100.8m fence length. The Brifen system when tested in Sweden at 100m length penetrated by 1.4m, achieving only a W5 rating. When taken in conjunction with the even greater discrepancy between testing and simulation for the Swedish design, and the fact that the discrepancy goes different ways for the two competitive products, one must suspect that the reported results contain test or parametric data not available to us.

<b>Test</b>	<b>Maximum Deflection</b>
Brifen, 3-Rope, Interwoven	1.265m
Brifen, 3-Rope, No Weave	1.227m
Swedish Design	1.744m

*Table 3: Comparative Fence Performance*

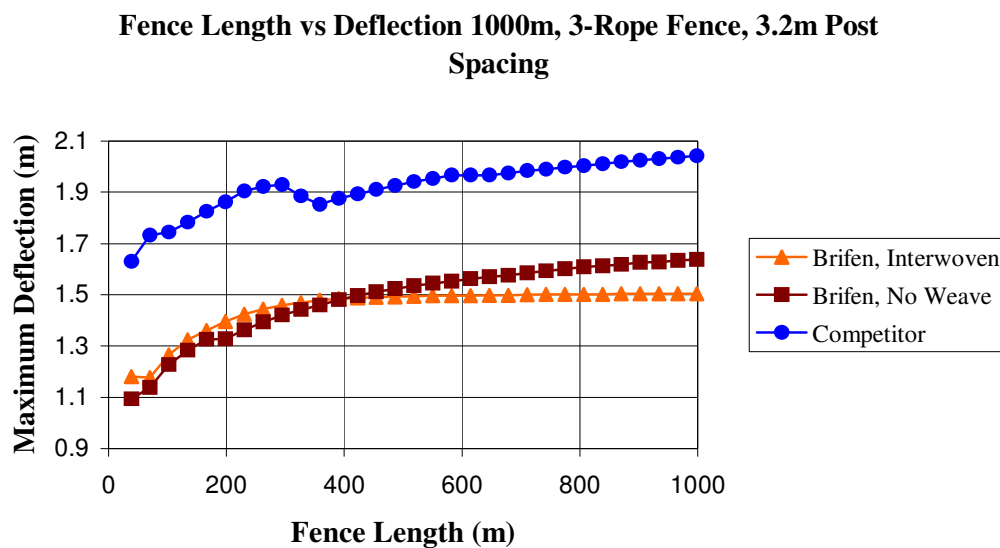
Also, Brifen engineers have recognised for some time that there is a fence-length sensitivity when testing wire rope safety fences. This is explainable by the simple fact that any rope is more flexible the greater is its length. Hence longer fences should be more flexible than shorter ones. This raises serious implications for using testing regimes of about 100m as a means of deciding whether or not a fence is suitable for actual roadway use.

Finally, industry experience with Brifen (based on testing fences of several hundred metres length) has encouraged the belief that the woven Brifen system is more effective than its un-woven counterpart. This belief is challenged by the simulation data of Table 3.

## Further Fence Simulations

In attempts to answer some of these questions, at least, we re-ran the original simulations for three different bay lengths and with fence lengths of up to 1000m<sup>1</sup>.

Figure 1 shows the results of varying just the fence length for all the original simulations. It demonstrates that, over fence lengths of up to 400m, the un-woven fence out-performs the woven fence. This is probably due to the woven fence releasing more slack as fence posts are knocked down, allowing greater deflection. The simulation of the Swedish design has much larger deflections for all fence lengths simulated.



*Figure 1: Maximum Vehicle Deflection for Varying Fence Length<sup>2</sup>*

For longer fence lengths, the relative deflection performance, woven versus un-woven, changes over. Figure 1 shows a cross-over point in maximum deflection once the fence has reached 400m in length where the maximum deflection with and without weaving is 1.45m. The trend for both weave patterns is that they increase in deflection as the fence length grows. The system with the woven ropes stops increasing at about 300m where the deflection levels off at a maximum of approximately 1.5m. Without weaving, the deflection continues rising, as elementary models of increasing lengths of

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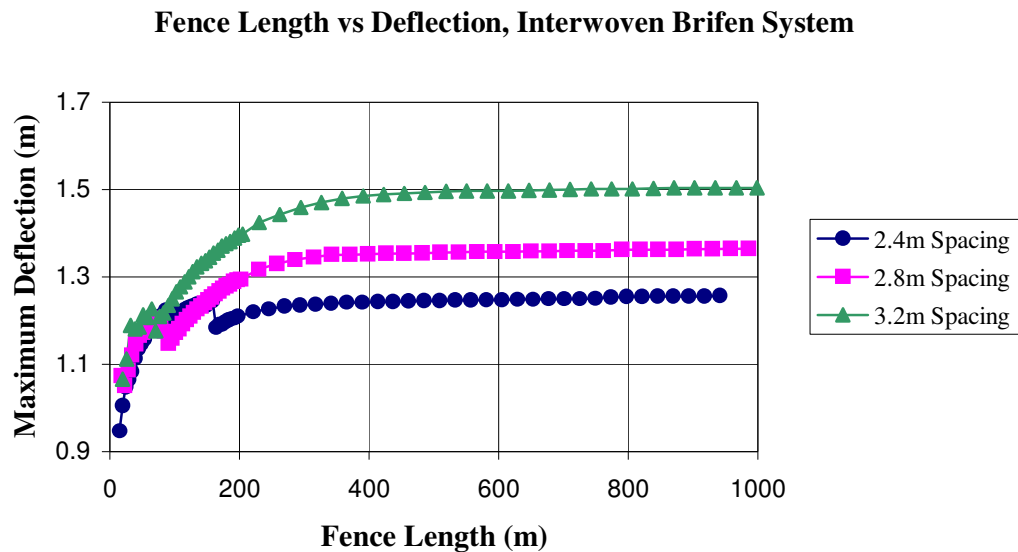
<sup>1</sup> The Brifsim2 software takes only seconds per run on a modern personal computer. The analysis programme described here involved 720 individual test scenarios. This is easily achievable in a set of batch runs of Brifsim2, with the whole set of results being available within one working day. Physical tests or full engineering simulations via finite element models come in at many thousand of pounds cost per test.

<sup>2</sup> The caption "Competitor" refers to the Swedish Design fence.

elastic rope predict. This suggests strongly that the woven system is better as a general rule.

Important observations for the design of fence tests arise from the different relationships displayed by different fence designs of different lengths. Woven fences with 3.2m post spacing have roughly constant performance for fences longer than about 300m. If these are tested at lengths significantly less than 300m, the test will under-predict the penetration of a real fence strung for more than 300m. Un-woven fences, of whatever design, decrease their performance without end as the fence lengthens. Without suitable fence length models, no test on a smaller fence can safely predict its performance in service with longer lengths.

Figure 2 illustrates the effect of reducing the distance between the posts as a means of keeping the deflection below 1.3m in the woven Brifen design. The fence stiffens as the post spacing reduces. All designs have the desirable asymptotic trend to a maximum value of deflection. Table 4 summarises the average and maximum deflection for the fences with different post spacing.



*Figure 2: Effect of Post Spacing on Maximum Deflection*

Post Spacing (m)	Average Deflection <sup>3</sup>	Maximum Deflection
3.2	1.42m	1.50m
2.8	1.30m	1.36m

<sup>3</sup> "Average" deflection in this context is the average of the deflections of all fence lengths between zero and 1000m, at that particular post spacing, per fence length simulated. For the particular runs illustrated in Figure 2, there were more runs done for lengths between zero and 200m than for any equivalent 200m length difference above 200m. This weights the average towards the small fence length region, typical of Swedish fence testing.

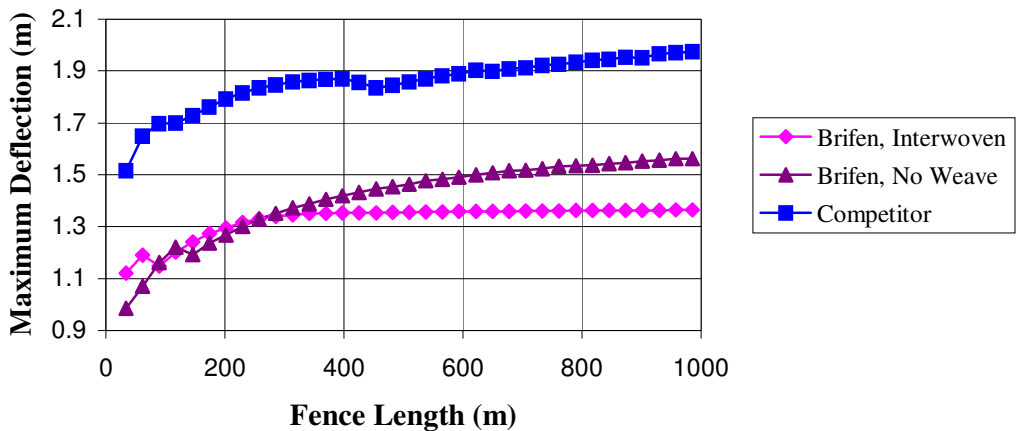
2.4	1.21m	1.26m
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**Table 4: Deflection Results at Different Post Spacing: Brifen woven fence**

Taken over 1000m the average value of deflection is 1.30m for a post spacing of 2.8m, which puts it on the limit of the W4 standard, which requires less than 1.3m. The maximum penetration, however, the one that is seen over most fence lengths, is slightly greater at 1.36m, just outside the limit. The shorter spacing of 2.4m between posts would bring performance within what is required at an average of 1.21m and a maximum of 1.26m.

Further data exploring the potential effectiveness of a design with 2.8m post spacing are set out in Figure 3. The three systems perform much the same way as for the 3.2m spacing designs, but now the deflections are smaller due to the reduced post spacing. There is, as before, a steady reduction of performance of the non-woven system with increasing fence length. Beyond the 600m-fence length, the deflection of the un-woven fence with 2.8m post spacing is greater than that of a woven fence with 3.2m post spacing.

**Fence Length vs Deflection 1000m, 3-Rope Fence, 2.8m Post Spacing**



*Figure 3: Maximum Vehicle Deflection for 2.8m Post Spacing*

## Verge Fence Designs

We explored a fence design that could safely catch aberrant vehicles flying out of control from a roadway towards a steep slope. We imagine the fence posts to be higher than normal, so that when they are embedded in the verge a small way down the slope, the ropes are at the normal Brifen height with respect to the plane in which the mass centre of the vehicle moves.

This provides the following input parameters for the fence.

Four Rope Fence, all ropes woven  
3.0m post spacing  
Rope Heights: 0.68m, 0.53m, 0.38m, 0.23m  
Posts: 3mm gauge  
Fence Length: 99m

We simulated the impacts of two vehicles into this fence, one being representative of small cars, the other of larger ones. Both vehicles were projected into the fence at 70 mph at an angle of 20°.

<b>Vehicle mass</b>	<b>Maximum Deflection</b>
900kg	1.141m
1500kg	1.576m

These figure, although large by the limits set for penetration of roadway medians, are quite reasonable for this application, where vehicle containment is the only criterion of acceptance.