ENERGY-ABSORBING BARRIER BEAMS SUSPENDED FROM LINEAR SUPPORTS

W. V. Brewer, University of Tulsa

ABRIDGMENT

THIS research explores the possibilities of improving total guardrail system performance by further exploitation of beam properties. Two performance aspects are of interest: a more gradual application of deceleration forces and efficient use of the beam to absorb a standard amount of energy (4,000-lb vehicle at 65 mph and 25-deg inclination). The first is accomplished by hypothesizing a standoff suspension separating beam from post. Substantial research effort has been directed toward devices that offer promise as energy-absorbing standoff suspensions for guardrail beams (1-6). (The desired linear load-deflection relation should be obtainable as a modification or combination of these or other available techniques but is beyond the scope of this research.) It will have an overall linear load-deflection relation (initially elastic but plastic in the limit) rather than the usual rigid-plastic one associated with posts having no suspension. An efficient beam will utilize elastic-plastic flexure to absorb energy and stiffness to spread the work out over the support system. The appropriate size beam for the most cost-effective configuration depends on performance requirements and component costs that are incorporated in a mathematical model.

SYSTEM MODEL

A synthetic model is used that satisfies the following performance requirements simultaneously and identically: Energy absorbed is the amount that is necessary to effect vehicle redirection, and maximum lateral deceleration level is 5 g. The model gives the beam size and suspension requirements. Beam deflections are minimally consistent with the preceding performance requirements.

The barrier system will be designed to use the beam in flexure and does not develop resultant tensile loads. Classical theory for a beam on an elastic foundation (7) and ideal beam theory of plastic-hinge structural analysis (8) are used in the description of beam behavior. A Winkler type of model (7, p. 197) is used for the vehicle.

Given the energy to be absorbed and permissible lateral g-level, we can generate a spectrum of barrier systems ranging from strong beam and weak post to strong post and weak beam all of which satisfy the given requirements identically. A parameter R relating the amount of plastic hinge present is convenient for classification of these results: $R < 1$, no hinge; $1 < R < 2.43$, 1 hinge; and $R > 2.43$, 3 hinges—hence large deflections. Small values of R produce systems with large beams and small-capacity (or more widely spaced) suspension-post assemblies; the opposite is true for large R-values.

COMPARISONS AND DISCUSSION

A spectrum of R-values is used to evaluate the cost-effective beam size from available component cost information. For a steel beam of box section, proportions have been adjusted to prevent section instability due to plastic flexure. Table 1 gives abbreviated results for the cost-effective system among those for systems having the extreme values of R. The following input data were used in deriving the results given in Table 1:

1. Impact conditions—velocity, 65 mph and 25 deg; lateral deceleration, 5 g; and vehicle weight, 4,000 lb;
2. Material or component capacities—yield strength, 60,000 psi; elastic modulus, 30,000 ksi; maximum load of post, 5,000 lb; and energy absorbed by vehicle, 5,625 ft-lb; and
3. Component costs—galvanized steel, 20 cents per pound; standoff suspension (estimate), $12 per unit; post and preparation of beam at point of attachment, $12 per post; installation, $18 per post; and total support cost, $42 per unit.

Though all 3 systems satisfy the same performance requirements, a poor balance between beam and supporting structure (as indicated by R) could be costly. In addition to higher first costs, systems having R-values greater than 2 become plastic when they are remote from the impact site, thus increasing beam replacement cost. A cost-effective system utilizes the support structure that is remote from the impact site to absorb energy and thus reduce total required capacity per unit length (note "effective length" in Table 1). This does not increase repair cost when the remote portions of both beam and standoff suspension are held within the initially elastic load range. Large values of R produce more severe slope discontinuities. The cost-effective beam is deeper, narrower, and lighter (10 in. by 4.6 in. by 0.19 in. and 18.8 lb/ft) than the beam (8 in. by 6 in. by ¼ in. and 22 lb/ft) in current service.

Large beam deflections (greater than 5 ft) are necessary to meet the required 5-g lateral deceleration limit under the stated conditions. Eight-ft deflections are the result of gradually applied deceleration forces in this initially linear system.

Greater post spacing results from improved performance and higher cost of the standoff suspension. Cost of the suspension is a matter of conjecture at this time. Higher cost would force the optimum to lower values of R.

CONCLUSIONS

Higher performance requirements for increased speed with reduced deceleration levels will necessitate barrier systems capable of large beam deflections. Automobiles are not capable of large enough deflections to absorb any significant portion of the total energy at required g-levels. Economics will force the use of systems that spread the work out over a large portion of the support structure (smaller R-values). A proper balance between beam and support structure is essential to cost-effective performance. Satisfaction of energy and deceleration requirements simultaneously and identically is a necessary but insufficient condition for the most cost-effective system.

Table 1. Model results.

	Output Data		
Factor	R = 1	R = 1.8	R = 2.4
Cost (dollar/ft)			
Beam	9.37	3.75	2.58
Support structure	1.24	3.70	5.37
Total	10.61	7.45	7.95
Weight of beam (lb/ft)	49.9	18.8	12.9
Slope at hinge (deg)	0.0	-8.68	-13.9
Box beam section dimensions (in.)			
Depth	16.1	10.1	8.42
Width	7.24	4.58	3.80
Thickness	0.296	0.187	0.155
Cross-sectional area	13.8	5.51	3.79
Performance dimensions (ft)			
Post spacing	36.2	11.4	7.91
Maximum deflection	9.52	8.13	8.27
Effective length[a]	342.0	127.0	91.4

[a]Distance between 2 points of zero beam deflection on either side of the maximum.

RECOMMENDATIONS

Beam interaction with other types of suspension-post models should be investigated where the beam dimensions are adjusted so that all variants satisfy the same performance requirements. Promising suspensions should be developed to the point where their costs can be included in optimization studies. Optimum beam section proportions (as opposed to size) are not the same for guardrails as for beams used in other applications and should be investigated further.

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