COST-EFFECTIVENESS OF GUARDRAIL-BRIDGERAIL TRANSITION IMPROVEMENTS: DOUBLE W-BEAM VERSUS DECREASED POST SPACING

by

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in cooperation with
NEBRASKA DEPARTMENT OF ROADS

CIVIL ENGINEERING DEPARTMENT
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UNIVERSITY OF NEBRASKA

Engineering Research Center
College of Engineering and Technology
University of Nebraska
Lincoln, Nebraska 68588

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ABSTRACT

Key Words: Guardrail, Roadside Safety, BARRIER VII

This study was initiated at the request of the Nebraska Department of Roads (NDR) to gain more insight into the performance characteristics of two guardrail-bridgerail transition systems; the AASHTO stiff-post system and the NDR "double" beam system. The stiff-post system provides larger size posts on reduced spacings; whereas, the NDR system installs another length of guardrail alongside the face of the existing guardrail with uniform 6 ft-3 in. post spacings. The NDR system eliminates the difficulty of increasing the stiffness of existing systems because of the concrete bridge abutments and/or wing walls restricting the placement of additional posts on reduced spacings.

The NDR system has been questioned by some engineers because its performance has not been verified by full-scale testing. Therefore, the objective of this study was to conduct a study of "limited" scope using the BARRIER VII computer program to ascertain the cost-effectiveness of the stiff-post system in comparison to the NDR "double" beam system. The study took into consideration the effects of two size automobiles impacting the quardrail transitions under all possible combinations of impact speed and angle.

The study showed that (1) the stiff-post system was not cost-effective because it produced more injury type accidents, (2) the stiff-post system resulted in larger exit angles thereby creating increased concern of secondary collisions with other vehicles, and (3) the structural adequacy of the guardrail-bridgerail connection in both systems was the single most important design element.

The findings of this study show that a reasonable doubt exists as to the cost-effectiveness of the AASHTO stiff-post system under a wide range of traffic impact conditions. Further research should be conducted to compare the performance characteristics of the two systems by means of full-scale testing and computer model simulations.

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INTRODUCTION

The current accepted practice in designing approach W-beam guardrail is to increase the stiffness of the guardrail by decreasing the post spacing and using larger size posts adjacent to a bridge structure. This design practice was established from the results of a "limited" number of full-scale crash tests using a large size automobile weighing 4,500 lbs under the extreme impact conditions of 60 mph and 25 deg.

In attempting to upgrade existing systems, the Nebraska Department of Roads (NDR) has often found that it was difficult to increase the stiffness of approach guardrail by adding posts because of the extended concrete foundation footings. As a compromise, the NDR has designed a transition section whereby the stiffness of the guardrail is increased by installing another length of guardrail alonside the face of the existing guardrail.

The NDR design has been questioned by some engineers because its performance has not been verified by full-scale crash tests. Therefore, the objective of this study was to conduct a study of limited scope using computer model simulations to ascertain the cost-effectiveness of decreasing the post spacing adjacent to a bridge structure in comparison to the NDR "double" beam design. This study will take into consideration the effects of different size automobiles impacting the approach guardrail under all possible combinations of impact speed and angle.

STUDY SITE

A plan view of the bridge approach guardrail site for this study is shown in Figure 1. The highway is classified as a 2-lane major arterial rural state highway that will carry a design hourly volume of 400 to 750. The traffic lanes are 12 ft wide and the paved shoulders are 8 ft wide.

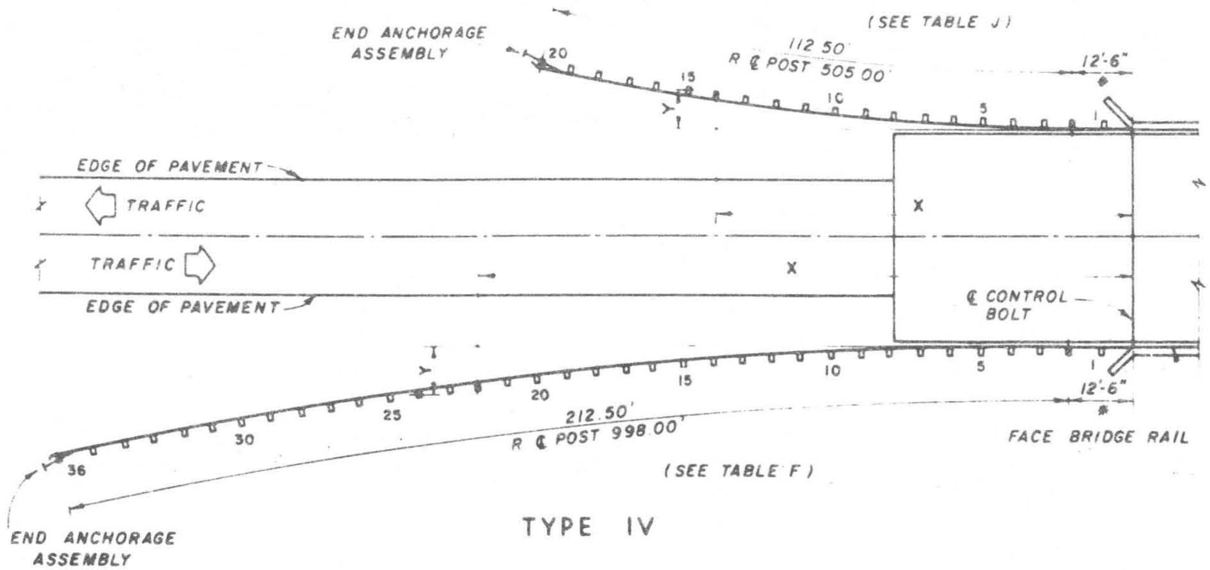
Details of the Type IV bridge approach guardrail are shown in Figure 2. The "double" section of guardrail extends over a length of 12 ft-6 in. and is bolted to 6 x 8 in. posts spaced 6 ft-3 in. on centers. A "special" end shoe is used to connect the guardrail to the concrete bridge parapet.

A plan view of the proposed improvement alternative is shown in Figure 3. This design is very similar to the AASHTO T1 (1) design. The 6 posts adjacent to the bridge have a reduced post spacing of 3 ft-1½ in. on centers, whereas, the size of the last 3 posts are larger 10 x 10 in. timbers.

NOTE

ALL DIMENSIONS ARE REFERENCED FROM THE FACE OF BRIDGE RAIL AT THE CONTROL BOLT IN THE GUARD RAIL CONNECTION TO THE ℄ OF THE POST

\# BRIDGE APPROACH SECTION.



TYPE IV

TABLE F		
POST NO.	X DISTANCE	Y OFFSET
1	6.25	1.25
2	12.50	1.25
3	18.74	1.27
4	24.98	1.33
5	31.23	1.43
6	37.47	1.56
7	43.71	1.74
8	49.94	1.95
9	56.18	2.21
10	62.42	2.50
11	68.65	2.83
12	74.88	3.20
13	81.11	3.61
14	87.34	4.06
15	93.56	4.55
16	99.78	5.07
17	106.00	5.64
18	112.21	6.24
19	118.42	6.89
20	124.62	7.57
21	130.82	8.29
22	137.02	9.05
23	143.21	9.85
24	149.39	10.68
25	155.58	11.56
26	161.75	12.47
27	167.92	13.43
28	174.08	14.42
29	180.24	15.45
30	186.39	16.52
31	192.53	17.62
32	198.67	18.77
33	204.80	19.95
34	210.92	21.17
35	217.03	22.43
36	223.14	23.73

TABLE J		
POST NO.	X DISTANCE	Y OFFSET
1	6.25	1.25
2	12.50	1.25
3	18.73	1.29
4	24.97	1.40
5	31.20	1.60
6	37.43	1.87
7	43.65	2.21
8	49.87	2.63
9	56.09	3.13
10	62.29	3.71
11	68.50	4.36
12	74.69	5.09
13	80.87	5.90
14	87.04	6.78
15	93.20	7.74
16	99.35	8.77
17	105.48	9.88
18	111.61	11.07
19	117.71	12.33
20	123.80	13.67

REV. No	DATE	DESCRIPTION OF REVISION
R1	10-10-74	ALT "C" POST - SPLICE BOLT SLOT

NEBRASKA DEPARTMENT OF ROADS

STANDARD PLAN No 704

SAFETY BEAM GUARD RAIL

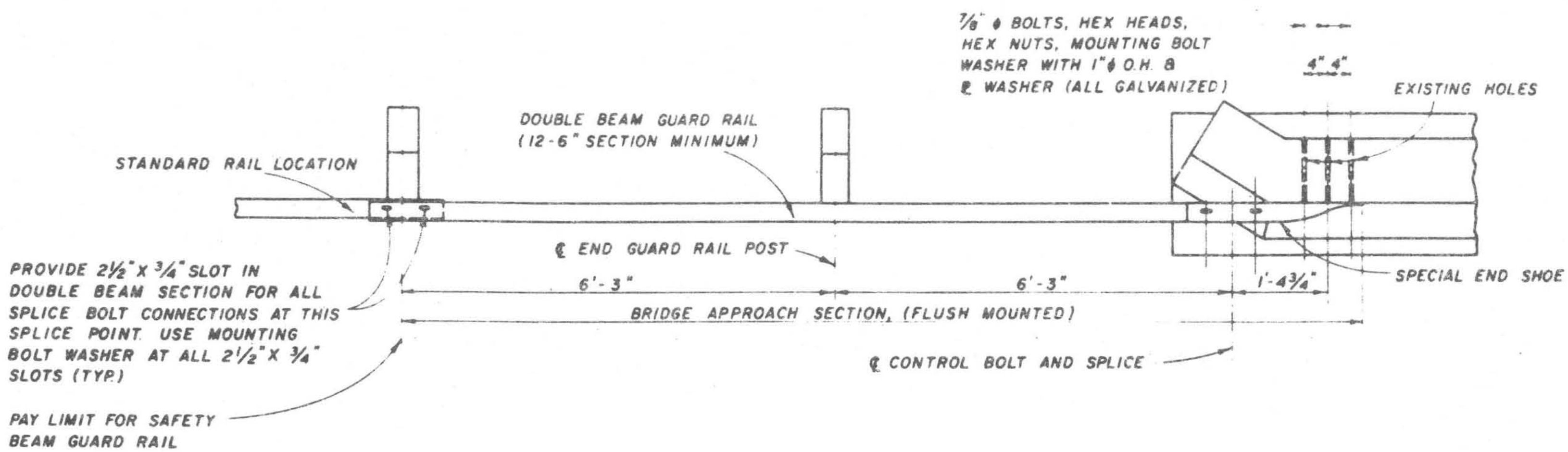
APPROVED: DECEMBER 21, 1973
DATE

Kenneth J. Gottula
ROADWAY DESIGN ENGINEER

SCALE AS SHOWN

3/6

FIGURE 1. PLAN VIEW OF EXISTING GUARDRAIL APPROACH STUDY SITE



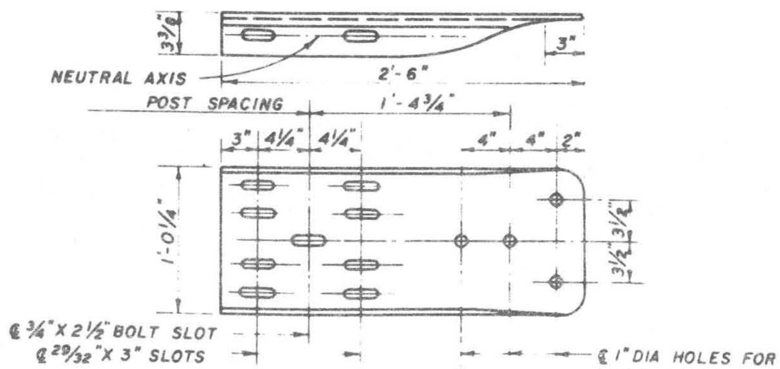
NOTES:

ALL WELDING DAMAGE TO GALVANIZED COATING SHALL BE REPAIRED BY APPLICATION OF GALVALOY AMCO NO. 321 OR ZRC IN ACCORDANCE WITH MANUFACTURERS RECOMMENDATION.

ALL HOLES AND BLOCK-OUTS IN CONCRETE ARE PART OF THE BRIDGE WORK AND ARE NOT PART OF THIS PLAN.

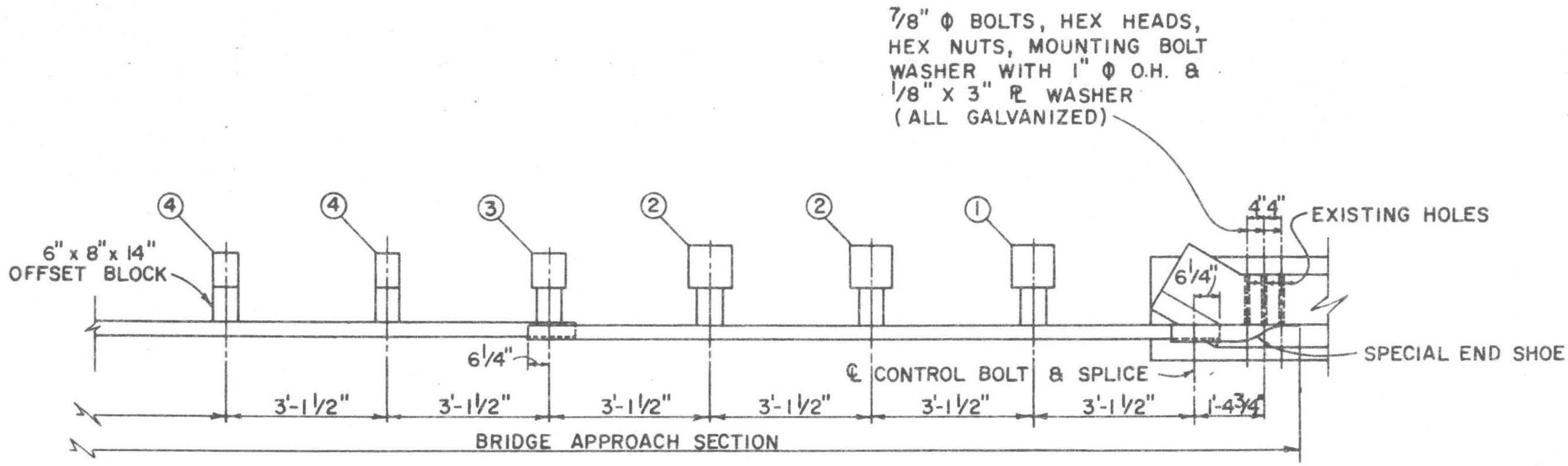
SPECIAL END SHOE SHALL BE 10 GAGE STEEL AND GALVANIZED IN ACCORDANCE WITH ASTM DESIGNATION A93 OR A123 WITH COATING CLASS 250.

ALL DOUBLE BEAM RAIL SHALL BE TACK WELDED AT APPROXIMATE 3' CENTERS, TOP AND BOTTOM.



SPECIAL END SHOE

FIGURE 2. DETAILS OF EXISTING DOUBLE BEAM APPROACH GUARDRAIL



POST No.

① —— 10"x 10"x 6' WOODEN POST REQUIRED - "OMIT IF IN CONFLICT WITH BRIDGE WING"

② —— 10"x 10"x 6' WOODEN POST REQUIRED

③ —— 8"x 8" x 6' WOODEN POST REQUIRED

④ —— 6"x 8" x 6' WOODEN POST REQUIRED

FIGURE 3. PLAN VIEW OF IMPROVEMENT ALTERNATIVE: REDUCED POST SPACINGS AND LARGER SIZE POSTS ADJACENT TO BRIDGE

COMPUTER MODEL OF AUTOMOBILE

During the past three decades, many highway organizations have relied heavily upon experience and judgment in the design of roadside appurtenances; and, trial and error full scale tests were often conducted to determine the feasibility of these appurtenances. Significant advancements in technology and an increase in safety have evolved from these efforts. However, this type of design approach appears to be insufficient by itself because one or more full scale tests were required to effectively evaluate the influence of any one variiable. Conducting many full scale tests can be both time consuming and costly.

Mathematical model simulation provides a rapid and economical method to investigate the many variables involved in a run-off-the-road automobile collision or maneuver. A limited number of full scale tests can then be conducted to confirm the simulation results. When supplemented by experience, judgment and tests, model simulation can be a very helpful tool in achieving efficient and safe designs.

BARRIER VII

The BARRIER VII program was utilized subsequently in this study to determine the dynamic effect of an automobile interacting with a traffic barrier system. BARRIER VII was developed by Powell (2,3).

The traffic barrier is idealized as a plane framework composed of elastic inelastic one-dimensional elements of a variety of types. The automobile is idealized as a plane rigid body surrounded by a cushion of springs. A large displacement dynamic structural analysis problem is solved by numerical methods.

The analysis is two-dimensional in the horizontal plane. Out-of-plane effects, which include vertical displacements of both the automobile and the barrier, are not considered. The automobile slides along the barrier, and the effects of normal force, friction forces, and wheel drag forces are considered in determining its motion. Data necessary for input to the program consists of the barrier configuration, the properties of the barrier members and automobile and the velocity and trajectory of automobile before impact. Output consists of barrier member forces, barrier deflections, time histories of automobile positions, and velocities and acceleration of automobile.

A final comment should be made about the BARRIER VII program. It is a two dimensional program and therefore placed limitations on this study. BARRIER VII cannot predict roll motion of the vehicle, wheel snagging or vehicle vaulting. BARRIER VII also will not predict situations where the vehicle could break through the guardrail. In all BARRIER VII simulations, the railing will return to the elastic state, even though at times there may be sufficient plastic hinges formed so as to create a local mechanism. As far as this study was concerned, all the guardrail performance runs were based on successful guardrail tests.

Output results from BARRIER VII that were of direct interest in this study were vehicle accelerations, exit angles, dynamic deflections, forces in the rail member adjacent to the guardrail to parapet connection, and damage to the guardrail system. The results for all the impact combinations are shown in a later section in Tables 3a, b, c, and d. Input vehicle and barrier properties and output data for a compact vehicle (2,250 lbs) impacting the stiffened guardrail approach under the impact conditions of 50 mph and 25 deg is presented in Appendix A.

In determining damage to the guardrail system, the BARRIER VII program will show whether a post has failed. The assessment as to rail damage can be made based on the deflections that occur in the system. The length of rail reported as damaged is in increments of 12.5 ft., since this would be the minimum length of rail that could realistically be replaced.

It was felt that the structural adequancy of the guardrail to parapet connection could be predicted with the force histories that the BARRIER VII program outputs. If any tensile force in the rail member directly adjacent to the parapet connection reached 80,000 lbs and was maintained for a few time steps, it would be assumed to cause the connection to reach yield and then fail.

SEVERITY OF AUTOMOBILE COLLISIONS WITH TRAFFIC BARRIERS

The severity of an automobile colliding with a traffic barrier was expressed in terms of a Severity-Index. The severity-index is computed as the ratio of the measured or computed resultant automobile acceleration to the resultant "tolerable" automobile acceleration that defines an ellipsoidal surface. This ratio can be expressed mathematically by Eq. 1. An in-depth discussion on the development of Eq. 1 was presented by Ross and Post (4) and Weaver (5).

$$SI = \frac{G_{\text{total Auto}}}{G_{\text{total Occupant}}} = \sqrt{\left[\frac{G_{\text{long}}}{G_{XL}}\right]^2 + \left[\frac{G_{\text{lat}}}{G_{YL}}\right]^2 + \left[\frac{G_{\text{vert}}}{G_{ZL}}\right]^2} \qquad \text{---Eq. 1}$$

where:

SI = Severity-Index

$G_{\text{total Auto}}$ = Resultant Auto Acceleration

$G_{\text{total Occupant}}$ = Resultant Tolerable Acceleration

G_{long} = Auto Acceleration along longitudinal x-axis

G_{lat} = Auto Acceleration along lateral y-axis

G_{vert} = Auto Acceleration along vertical z-axis $\overset{\text{set}}{=\!=} 0$

G_{XL} = Tolerable Acceleration along x-axis

G_{YL} = Tolerable Acceleration along y-axis

G_{ZL} = Tolerable Acceleration along z-axis

The severity-index computations in the subsequent work will be based on accelerations tolerable to an unrestrained occupant, and the automobile accelerations will be averaged over a time duration of 50 msec. The relationship between severity-index and injury levels will be discussed in a later section. Tolerable accelerations suggested by Weaver (5) for use in the severity-index equation are shown in Table 1.

TABLE 1

TOLERABLE AUTOMOBILE ACCELERATIONS
(After Weaver 5)

Degree of Occupant Restraint	Accelerations G_{YL}	G_{XL}	G_{ZL}
Unrestrained	5	7	6
Lap Belt Only	9	12	10
Lap Belt and Shoulder Harness	15	20	17

Since BARRIER VII is a two-dimensional program, the vertical acceleration term (G_{vert}) in Eq. 1 was set equal to zero.

SEVERITY-INDEX RELATIONSHIPS

The criteria used in the majority of the research work conducted during the past decade for evaluating the safety aspects of roadside hazard improvements were based on levels of vehicle acceleration that would be tolerable to an unrestrained occupant. One method used to accomplish this task was to define a Severity-Index which was computed as the ratio of the measured resultant automobile acceleration to the resultant "tolerable" automobile acceleration (see Eq. 1). An improvement that resulted in a Severity-Index value of one or less was considered to be safe; whereas, an improvement resulting in a Severity-Index value greater than one was considered to be unsafe. The work to follow will expand the existing technology to include the probability of occurrence of roadside injury type accidents.

Injury Probability

An indepth discussion on a tentative relationship between Severity-Index and the probability of occurrence of injury type accidents was recently presented by Post (6) to the Transportation Research Board. The relationship established for injury probability is shown in Table 2. For simplicity purposes in this study, the histogram relationship was approximated by the two linear relationships as shown in Figure 4.

TABLE 2

RELATIONSHIP BETWEEN SEVERITY-INDEX

AND PROBABILITY OF INJURY ACCIDENTS

(AFTER POST 6)

Severity-Index (SI)	Probability of Injury Accident
SI ≤ 0.5	0.1
0.5 < SI ≤ 1.0	0.3
1.0 < SI ≤ 1.5	0.5
1.5 < SI ≤ 2.0	0.7
2.0 < SI ≤ 2.5	0.8
2.5 < SI	1.0

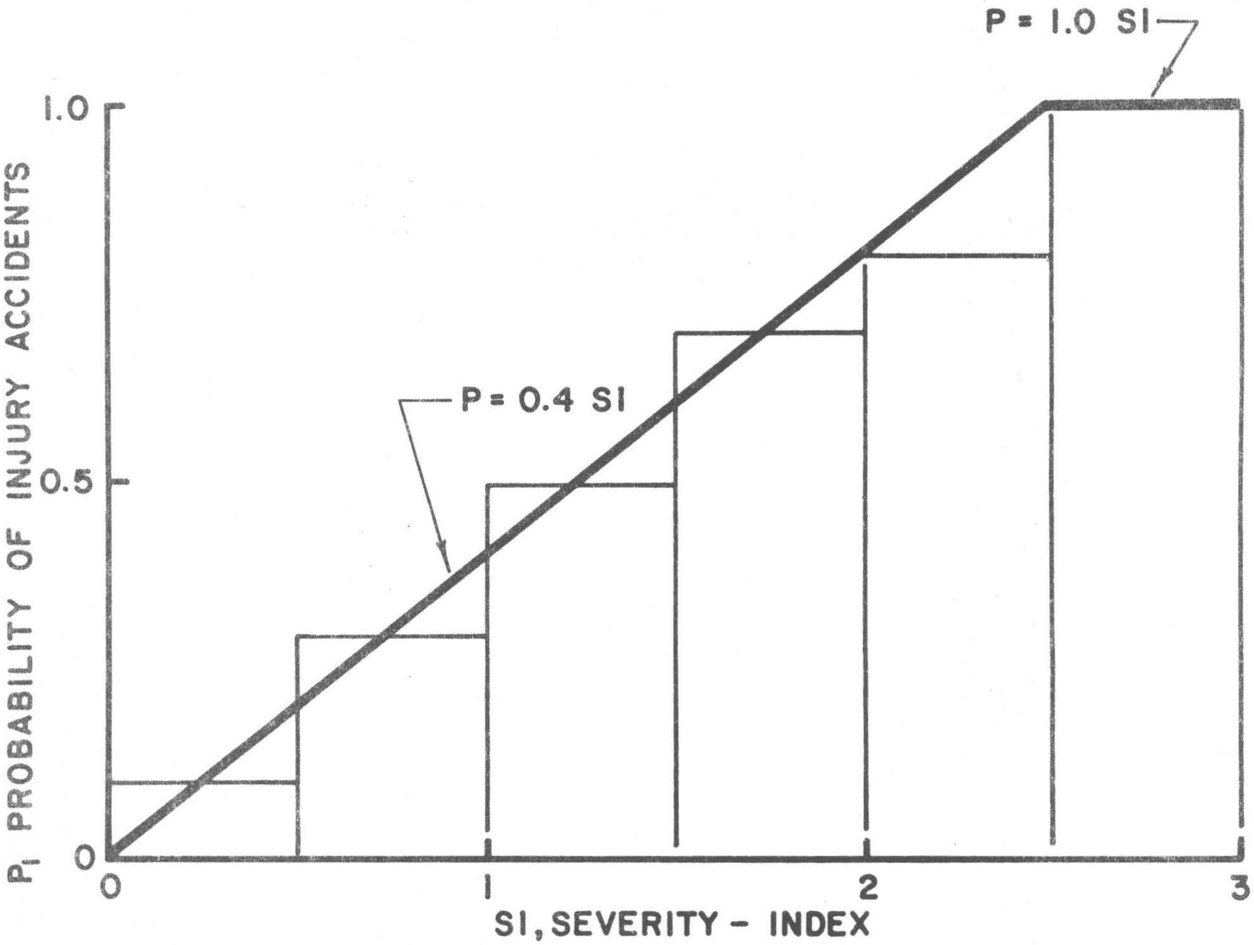


FIGURE 4. RELATIONSHIP BETWEEN SEVERITY-INDEX AND PROBABILITY OF INJURY ACCIDENTS

RESULTS OF BARRIER VII SIMULATIONS

Two size automobiles were used in making this study. The standard size vehicle (3,820 lbs) and the increasingly popular compact vehicle (2,250 lbs). Three impact speeds (40, 50, and 60 mph) and 4 impact angles (10, 15, 20, and 25 deg) were considered.

Point of Vehicle Impact

All of the impact combinations had an initial impact location of 21.9 ft upstream from the concrete parapet connection. The single impact location was chosen such that there would be adequate time and distance for successful redirection of the automobile under all conditions considered in this study, if indeed redirection were to occur. In the case of the lower speeds and lower impact angles, it would have been possible to move the initial impact location closer to the parapet and still have had successful redirection. It was felt that there would be a "trade off" as far as hazardousness was concerned in these cases when comparing the existing system versus the stiffened post system. Certainly the stiffened post system would yield significantly higher accelerations, whereas the existing system would seem likely to approach the situation where large enough forces would occur in the rail near the parapet connection so as to cause failure of the guardrail to parapet connection. In the former case, higher severities occur due to significant increases in accelerations, and in the latter case the higher severities come about because of the increased likelihood of impact with the parapet. It therefore seemed justified to select a single location of impact for all impact combinations based on the above discussion.

Guardrail-Parapet Connection

One point that needs to be raised from the discussion above was the importance of the guardrail to parapet connection. The connection is required to withstand an 80,000 lb load. As can be seen in Tables 3a, b, c, and d the tensile forces in the guardrail adjacent to the connection in some cases get quite high. It becomes very important then that the design engineer look very carefully at the structural details on the connection. This means making sure that not only are there an adequate number of bolts and a structurally adequate rail for the connection, but also making certain of the strength of the parapet that will be receiving these rather large forces. Any time that the connection fails, there is an almost certain chance of impact with the parapet and a 100% probability of injury (PI).

The critical consideration in the guardrail transition design is the guardrail to parapet connection. It would appear then, that if upgrading of a transition section were required, the stiffened post system would be the best solution if there were any question about the structural adequacy of the guardrail to parapet connection. This is owing to the fact that the stiffened post system develops smaller tensile forces in the rail at the connection than the existing system, therefore decreasing the chance for connection failure.

Vehicle Redirection Characteristics

The redirection characteristics of the two systems considered in this study were of importance, since a higher exit angle following impact with a guardrail increases the chance of the automobile being directed over into traffic in the opposing lane. It was interesting to note that the stiffened post system generates higher exit angles than the existing system. The explanation for this behavior comes from the fact that in the stiffened post system, larger normal forces than are found in the existing system were developed between the guardrail system and the automobile. These larger forces tend to redirect the automobile at a higher yaw rate than those found in the existing system. In some cases there were secondary impacts occurring in the stiff post system interactions. The automobile was in contact initially with the front portion of the car and the large normal forces quickly increase the yawing motion until the rear portion of the vehicle suddenly impacts with the rail. The cases where secondary impact occurs are noted in Tables 3b and d.

Shown below in Figure 5 are some plots which show a typical comparison between the redirection characteristics of a vehicle interacting with the stiff post system and the existing system. The data was obtained from the simulations made with the compact automobile at 40 mph and 25 deg. The point being monitored was the center of gravity of the vehicle.

Severity-Indicies

There were two cases where the severity index (SI) deviated from a consistent pattern. For the large automobile (3,820 lbs) impacting the existing system at 20 and 25 degrees, the SI's were reported as larger than for the same vehicle impacting the stiff post system. An apparent explanation for this was that the large vehicle at these large encroachment angles had penetrated far enough into the guardrail system so that it was "picking up" the contribution of the stiffness of the guardrail to parapet connection more so than the vehicle under the other impact combinations. The maximum accelerations for these two unique cases then, were occurring at a later time during the interaction with the guardrail system than for the other cases.

TABLE 3a RESULTS OF BARRIER VII SIMULATION

Type Guardrail Transition: Existing

Size Automobile: 2,250 lbs

Impact Conditions		Downstream Anchor Structurally Adequate[1]		Max. Vehicle Accelerations[2] (G's)		Severity Index[3] (SI)	Max. Tensile Force in End Rail (kips)	Guardrail Dynamic Displacement (ft)	Vehicle Exit Angle (deg)	Guardrail Damage		Probability of Injury[4] (PI)
Speed (mph)	Angle (deg)	Yes	No	Lat.	Long.					No. Post Failed	Length (ft)	
40	10	X		2.22	1.34	0.48	0.1	0.20	1.5	0	12.5	0.19
	15	X		3.28	2.37	0.78	0.2	0.34	2.9	0	25.0	0.30
	20	X		4.40	3.75	1.03	1.3	0.52	5.4	0	25.0	0.41
	25	X		4.54	5.02	1.16	8.2	0.94	10.9	1	25.0	0.46
50	10	X		2.91	1.70	0.63	0.1	0.27	1.7	0	25.0	0.25
	15	X		4.25	2.89	0.95	1.6	0.49	3.4	0	25.0	0.38
	20	X		5.32	2.67	1.26	5.8	0.78	6.4	0	25.0	0.50
	25	X		4.72	5.93	1.27	20.8	1.56	7.7	3	37.5	0.51
60	10	X		3.80	2.17	0.82	0.4	0.38	1.3	0	25.0	0.33
	15	X		5.73	3.98	1.28	2.3	0.67	3.4	0	25.0	0.51
	20	X		5.48	5.44	1.34	18.6	1.51	6.0	3	37.5	0.54
	25	X		5.78	7.37	1.56	30.6	1.95	6.0	3	37.5	0.62

1. Anchor assumed to fail at tensile load of 80,000 lbs., and PI $\overset{\text{set}}{=}$ 100%.
2. Vehicle accelerations at C.G. averaged over time duration of 50 msec.
3. Severity-Index computed by Equation 1.
4. Injury Probability obtained from Figure 4.

TABLE 3b RESULTS OF BARRIER VII SIMULATIONS

Type Guardrail Transition: Stiffened Post

Size Automobile: 2,250 lbs.

Impact Conditions		Downstream Anchor Structurally Adequate[1]		Max. Vehicle Accelerations[2] (G's)		Severity Index[3] (SI)	Max. Tensile Force in End Rail (kips)	Guardrail Dynamic Displacement (ft)	Vehicle Exit Angle (deg)	Guardrail Damage		Probability of Injury[4] (PI)
Speed (mph)	Angle (deg)	Yes	No	Lat.	Long.					No. Post Failed	Length (ft)	
40	10	X		2.53	1.57	0.55	0.1	0.18	1.8*	0	12.5	0.22
	15	X		3.90	2.85	0.88	0.1	0.21	3.7*	0	12.5	0.35
	20	X		5.34	4.68	1.26	0.2	0.33	7.5*	0	12.5	0.50
	25	X		7.20	7.62	1.81	1.3	0.55	16.0*	0	25.0	0.72
50	10	X		3.50	2.12	0.76	0.0	0.16	1.9	0	12.5	0.30
	15	X		5.54	3.92	1.24	0.2	0.32	4.4	0	12.5	0.50
	20	X		7.94	6.75	1.86	0.6	0.51	9.0*	0	12.5	0.74
	25	X		7.40	9.03	1.96	11.5	1.15	14.6*	2	25.0	0.78
60	10	X		4.64	2.72	1.00	0.2	0.21	2.1	0	12.5	0.40
	15	X		6.33	4.32	1.41	0.2	0.38	4.4	0	12.5	0.56
	20	X		9.19	8.54	2.21	4.9	0.75	9.8	1	25.0	0.88
	25	X		8.23	10.60	2.24	19.3	1.54	15.7	3	25.0	0.90

1. Anchor assumed to fail at tensile load of 80,000 lbs., and PI $\overset{\text{set}}{=}$ 100%.
2. Vehicle accelerations at C.G. averaged over time duration of 50 msec.
3. Severity-Index computed by Equation 1.
4. Injury Probability obtained from Figure 4.

* Secondary Impact.

TABLE 3c RESULTS OF BARRIER VII SIMULATIONS

Type Guardrail Transition: Existing

Size Automobile: 3,820 lbs.

Impact Conditions		Downstream Anchor Structurally Adequate[1.]		Max. Vehicle Accelerations[2.] (G's)		Severity Index[3.]	Max. Tensile Force in End Rail	Guardrail Dynamic Displacement	Vehicle Exit Angle	Guardrail Damage		Probability of Injury[4.]
Speed (mph)	Angle (deg)	Yes	No	Lat.	Long.	(SI)	(kips)	(ft)	(deg)	No. Post Failed	Length (ft)	(PI)
40	10	X		2.05	1.29	0.45	0.4	0.37	3.3	0	25.0	0.18
	15	X		2.93	2.26	0.67	3.6	0.63	7.7	0	25.0	0.27
	20	X		2.99	2.86	0.72	16.8	1.34	10.0	2	25.0	0.29
	25	X		2.92	4.27	0.84	27.7	1.83	14.0	3	37.5	0.34
50	10	X		2.80	1.73	0.61	1.2	0.48	3.3	0	25.0	0.24
	15	X		3.76	3.07	0.87	12.0	0.95	6.7	1	25.0	0.35
	20	X		3.19	3.66	0.83	20.7	1.85	10.8	3	37.5	0.32
	25	X		4.08	4.26	1.02	50.1	2.49	16.3	3	37.5	0.41
60	10	X		3.71	2.10	0.80	2.2	0.58	2.8	0	25.0	0.32
	15	X		4.15	3.50	0.97	23.9	1.41	8.9	2	25.0	0.39
	20	X		9.03	7.81	2.12	51.3	2.33	13.1	3	37.5	0.95
	25	X		8.50	18.09	3.09	72.2	3.09	21.5	5	50.0	1.00

1. Anchor assumed to fail at tensile load of 80,000 lbs., and PI $\stackrel{\text{set}}{=}$ 100%
2. Vehicle accelerations at C.G. averaged over time duration of 50 msec.
3. Severity-Index computed by Equation 1.
4. Injury Probability obtained from Figure 4.

* Secondary Impact.

TABLE 3d RESULTS OF BARRIER VII SIMULATIONS

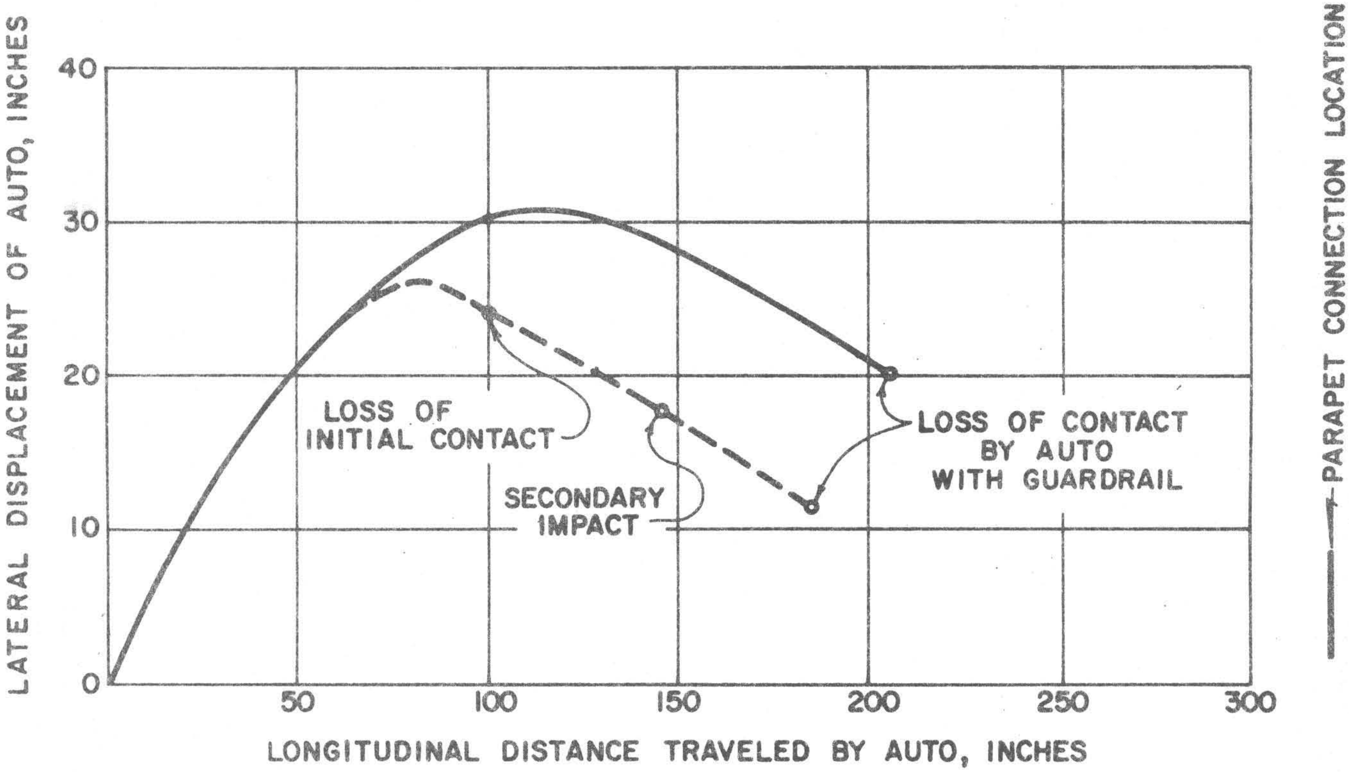
Type Guardrail Transition: Stiffened Post

Size Automobile: 3,820 lbs.

Impact Conditions		Downstream Anchor Structurally Adequate[1.]		Max. Vehicle Accelerations[2.] (G's)		Severity Index[3.] (SI)	Max. Tensile Force in End Rail (kips)	Guardrail Dynamic Displacement (ft)	Vehicle Exit Angle (deg)	Guardrail Damage		Probability of Injury[4.] (PI)
Speed (mph)	Angle (deg)	Yes	No	Lat.	Long.					No. Post Failed	Length (ft)	
40	10	X		2.52	1.57	0.55	0.2	0.19	2.9*	0	12.5	0.22
	15	X		3.81	2.92	0.87	0.4	0.37	6.4*	0	12.5	0.35
	20	X		5.17	4.88	1.25	1.7	0.63	14.5*	0	12.5	0.50
	25	X		4.06	5.41	1.12	17.6	1.39	21.6*	3	25.0	0.45
50	10	X		3.46	2.11	0.75	0.2	0.24	3.1	0	12.5	0.30
	15	X		5.43	3.98	1.23	0.5	0.45	7.2*	0	12.5	0.49
	20	X		5.25	5.37	1.31	14.6	1.33	15.4	3	25.0	0.52
	25	X		4.61	6.73	1.33	28.8	1.87	25.0*	4	25.0	0.53
60	10	X		4.78	2.83	1.04	0.1	0.33	3.2	0	12.5	0.42
	15	X		6.25	4.86	1.43	5.2	0.75	8.8	2	25.0	0.57
	20	X		4.97	5.95	1.31	22.9	1.70	13.8	5	25.0	0.52
	25	X		5.32	8.19	1.58	38.6	2.32	28.0	5	37.5	0.63

1. Anchor assumed to fail at tensile load of 80,000 lbs., and PI $\overset{\text{set}}{=}$ 100%.
2. Vehicle accelerations at C.G. averaged over time duration of 50 msec.
3. Severity-Index computed by Equation 1.
4. Injury Probability obtained from Figure 4.

* Secondary Impact.



NOTE : ALL DATA POINTS ARE WITH RESPECT TO AUTO CENTER OF GRAVITY

EXISTING SYSTEM

STIFFENED SYSTEM

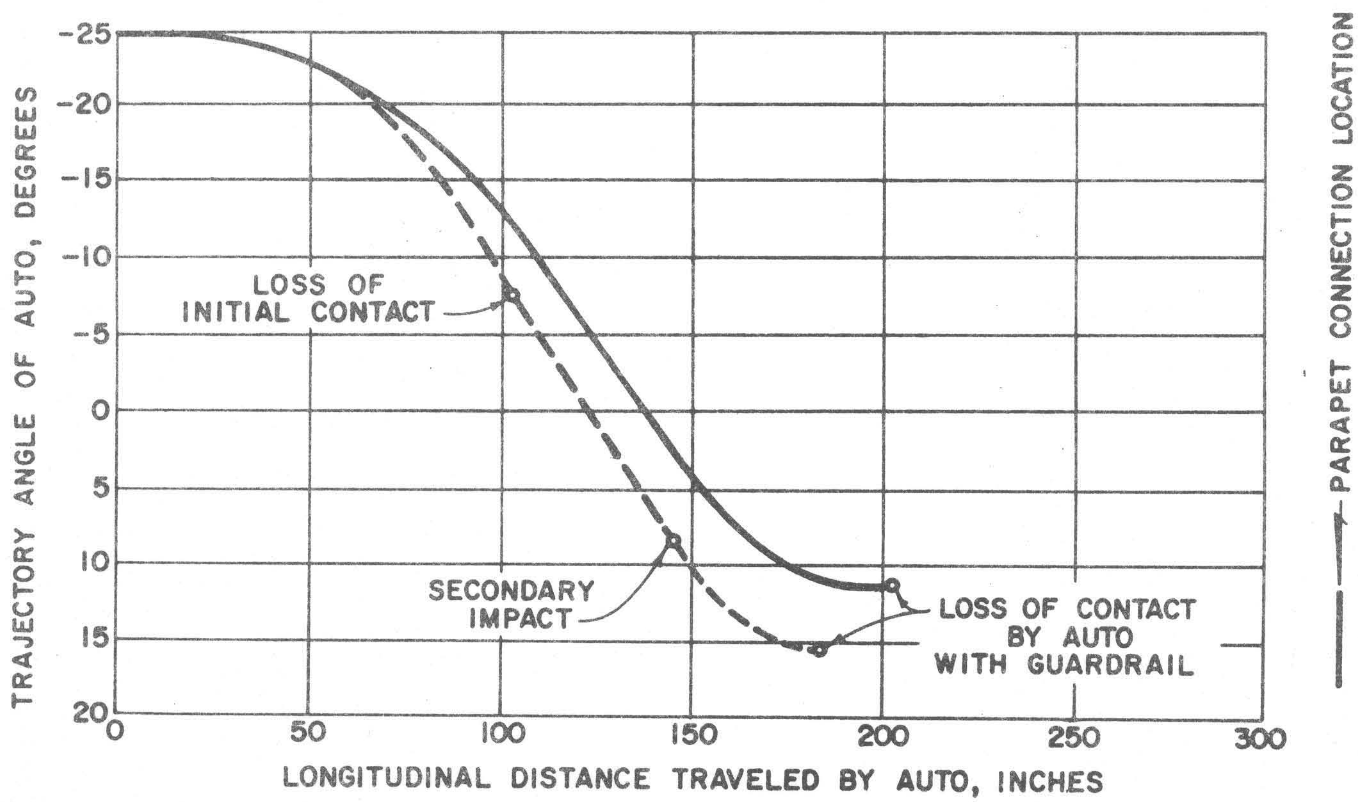


FIGURE 5. AUTOMOBILE (2,250 LBS.) TRAJECTORIES UNDER IMPACT CONDITIONS OF 40 M.P.H. & 25 DEGREES

IMPACT CONDITION PROBABILITIES

The impact condition probabilities were computed by combining distributions of vehicle speeds and encroachment angles. The vehicle speed distribution used was obtained from an analysis of spot speed data collected on 2-lane major arterial rural highway sections by the Nebraska Department of Roads. It was determined that vehicle speeds on these sections were normally distributed with a mean speed of 55.4 mph and a standard deviation of ± 4.6 mph. The impact angle distribution used was that reported by Hutchinson and Kennedy for median encroachments (7).

Assuming that these two distributions were completely independent, they were combined. The combined distribution of vehicle speeds and impact angles was then used to compute the impact condition probabilities shown in Table 4. These probabilities indicate that the most likely impact condition is a speed-angle combination of 55-65 mph and less than 7.5 degrees.

Using the point mass model presented by Ross (8), it was determined that some high-speed, high-angle impacts were not possible. However, because of the lack of encroachment data on speed-angle combinations to support this conclusion, it was decided that adjustment of the impact condition probabilities to account for the apparent impossibility of high-speed, high-angle impacts was not warranted.

TABLE 4. IMPACT CONDITION PROBABILITIES

Vehicle Speed (mph)	IMPACT ANGLE (DEG)					
	<7.5	7.5-12.5	12.5-17.5	17.5-22.5	22.5-27.5	>27.5
<45	0.006	0.002	0.001	0.00	0.00	0.000
45-55	0.217	0.090	0.054	0.036	0.023	0.032*
55-65	0.249	0.104	0.062	0.041	0.026*	0.036*
65-75	0.009	0.004	0.002	0.001*	0.001*	0.001*
>75	0.000	0.000	0.000	0.000	0.000	0.000

*Condition not possible according to point mass model.

EVALUATION OF IMPROVEMENT ALTERNATIVES

Roadside safety improvement programs must compete with other ongoing highway programs for the limited funds available. The "cost-effectiveness" method of analysis was used to compare the improvement alternatives of making the transition from the semi-rigid W-beam guardrail to the rigid concrete bridge parapet. The cost-effectiveness method is a management tool for providing the highway administrator with a means of evaluating safety improvement alternatives on a common data base to realize the greatest return on the investment to reduce injury accidents.

Cost-Effectiveness Analysis

The cost-effectiveness analysis conducted in this study was based on the cost-effectiveness priority approach formulated by Glennon (9), and implemented in Texas for managing roadside safety improvement programs on both non-controlled and controlled access highways (10). The cost-effectiveness measure used in this approach was:

Cost-Effectiveness = annualized cost of improvement per unit hazard reduction achieved

= Cost to eliminate one injury (fatal or non-fatal) accident

The measure of effectiveness was defined as the difference between the hazard indices before and after an improvement expressed in terms of the number of fatal and non-fatal accidents per year. Thus, in order to apply the cost-effectiveness priority approach in this analysis it was necessary to compute the hazard-index for each improvement and its annualized costs.

Hazard-Index

The hazard-index was computed for the improvement alternative using the following equation:

$$H = \frac{E_f(D)(P)(L)}{5280}\left[0.60\ H_1 + 0.40\ H_2\right] \qquad \text{---Eq. 2}$$

where:

H = hazard-index for each improvement alternative (injury accidents per year)

H_1 = hazard-index contribution for impacting vehicles weighing more than 2,250 lbs (assumed as 60%)

$= \sum_{\theta} \sum_{V} [(SP)(PI)]$

H_2 = hazard-index contribution for impacting vehicles weighing less than 2,250 lbs (assumed as 40%)

$= \sum_{\theta} \sum_{V} [(SP)(PI)]$

E_f = encroachment frequency (see Figure 6a)

D = directional traffic split = 1/2

P = lateral impact probability at some offset distance (see Figure 6b)

L = effective length of guardrail transition = 25 ft

SP = impact condition probability for each combination of speed and angle (see Table 4)

PI = injury accident probability for each combination of speed and angle severity-index for a certain size vehicle (see Figure 4)

Θ = vehicle impact angle = 10, 15, 20, and 25 deg

V = vehicle impact speed = 40, 50, and 60 mph

Encroachment Frequency

Knowledge of the frequency at which vehicles encroach on the roadside is very limited. Therefore, the encroachment frequency used by Glennon (9) was assumed to be applicable for the purpose of this analysis. The relationship between encroachment frequency and ADT is shown in Figure 6a. The ADT for the study site was assumed to be 7,500 vpd which will result in an encroachment frequency of:

$$E_f = 1.1 + (0.000415)ADT \qquad \text{---Eq. 3}$$

$$= 4.2 \text{ encroachments per year per mile}$$

Lateral Impact Probability

Given that an encroachment has occurred, the probability of a vehicle impacting a roadside obstacle decreases as the distance from the edge of the traveled roadway increases. Lateral inpact probabilities were obtained from the relationship used by Glennon (9) in Figure 6b.

Collision Maintenance Costs

The collision maintenance cost was computed for the improvement alternative using the following equation:

$$CM = \frac{E_f(D)(P)(L)}{5280} [0.60\ CM_1 + 0.40\ CM_2] \qquad \text{---Eq. 4}$$

where:

C = annualized collision maintenance cost

CM_1 = annualized collision maintenance cost contribution for vehicles weighing more than 2,250 lbs

$$= \sum_{\theta} \sum_{V} [(SP)(CS)]$$

CM_2 = annualized collision maintenance cost contribution for vehicles weighing less than 2,250 lbs

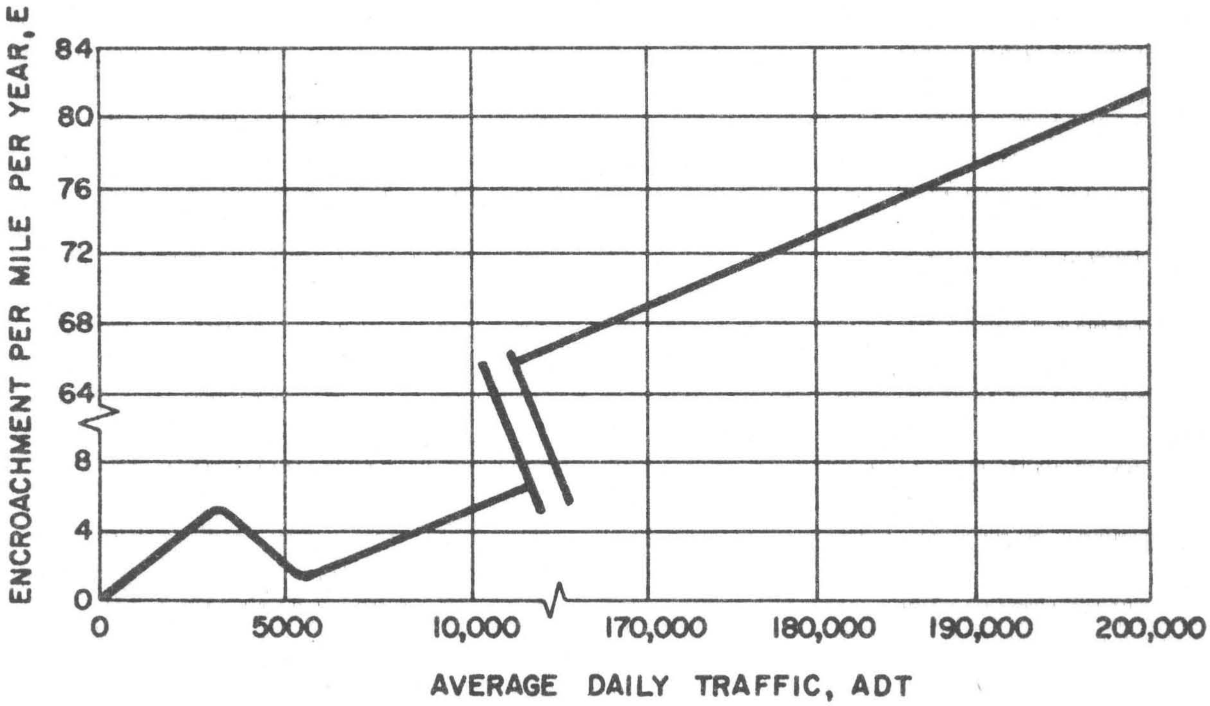


FIGURE 6a. ROADSIDE ENCROACHMENT FREQUENCY. SOURCE: HUTCHINSON AND KENNEDY (7)

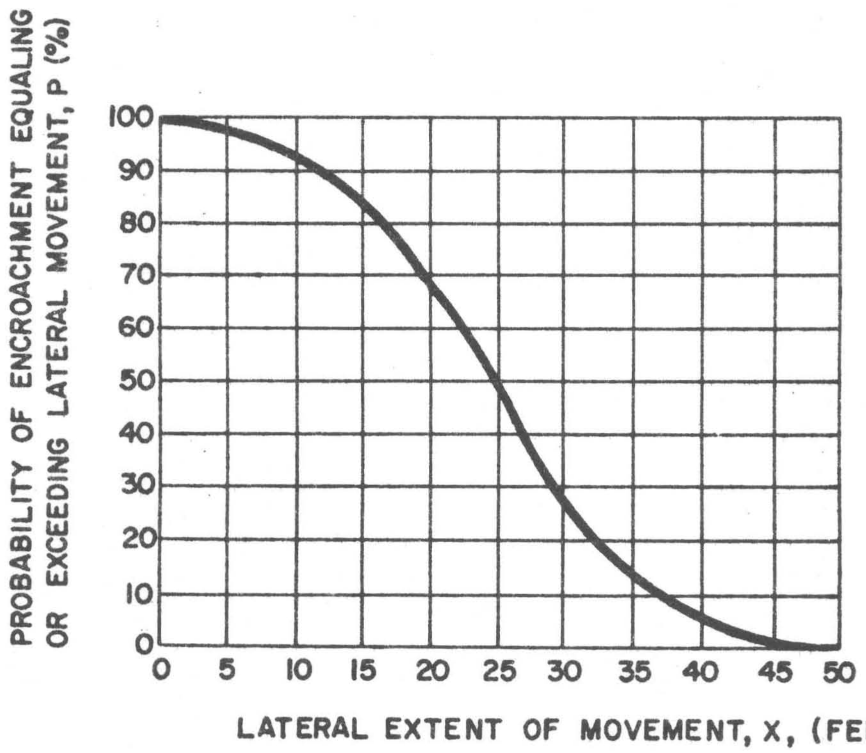


FIGURE 6b. DISTRIBUTION OF LATERAL DISPLACEMENTS OF ENCROACHING VEHICLES. SOURCE: HUTCHINSON AND KENNEDY (7)

$$CM_2 = \sum_{\theta}\sum_{V} [(SP)(CS)]$$

CS = annualized collision maintenance cost for each combination of impact speed and angle

All the remaining terms in Eq. 4 have been previously defined in Eq. 2.

Evaluation

As defined earlier, cost-effectiveness was described as the annualized cost of an improvement per unit hazard reduction achieved.

The measure of effectiveness was defined as the difference between the hazard indicies before and after an improvement. Effectiveness can be computed from the following equation:

$$E = H_{Exist.} - H_{Impr.} \qquad \text{---Eq. 5}$$

where;

E = Effectiveness (hazard reduction)

$H_{Exist.}$ = Hazard-Index of Existing System

$H_{Impr.}$ = Hazard-Index of Stiffened System

The annualized improvement costs consider both capital costs and collision maintenance costs. Normal maintenance costs were assumed to be small and neglected. The costs can be computed from the following equation:

$$C = CI_{Impr.} + CM_{Impr.} - CM_{Exist.} \qquad \text{---Eq. 6}$$

where:

C = Annualized Cost of Improvement

$CI_{Impr.}$ = Annualized Capital Cost of Improvement

$CM_{Impr.}$ = Annualized Collision Maintenance Cost of Improvement

$CM_{Exist.}$ = Annualized Collision Maintenance Cost of Existing

Results of the cost-effectiveness evaluation are summarized in Table 5. As can be seen from Eq. 5, the improvement alternative was not cost-effective because there was no reduction in the hazard index; in fact the stiffened guardrail system not only did not exhibit a reduction of hazard index but rather indicated a slight increase. This indicates that the probability of a higher incidence of injury accidents exists.

TABLE 5

RESULTS OF COST-EFFECTIVENESS EVALUATION FOR EACH GUARDRAIL APPROACH TO A BRIDGE

ADT = 7,500

E_f = Encroachments/mi/yr

Aternative	Lateral Offset Distance (ft)	Lateral Impact Probability	Hazard-Index (Injury Accidents/yr	Capital Costs[1.]		Collision Maintenance Costs[1.] ($/yr)	Cost Effectiveness (C/E)
				($)	($/yr)		
Existing "Double" W-Beam	9	0.94	0.0034	--	--	1	---
Reduced Post Spacing and Larger Size Posts	9	0.94	0.0041	540	59	1	Not Cost Effective[2]

Notes

1. Annualized costs were based on a 20 yr. service life, 9% interest rate, and zero salvage value (crf = 0.1095)

2. Not Cost-Effective because $H_{Impr.} > H_{Exist.}$

SUMMARY AND CONCLUSIONS

This study on the cost-effectiveness of guardrail-bridgerail transition areas was conducted by the University of Nebraska in cooperation with the Nebraska Department of Roads (NDR).

The NDR requested the research study in order to gain more insight into the performance characteristics of two guardrail transition systems; the AASHTO stiff-post system and the existing NDR double beam system. The stiff-post system increases the stiffness of the guardrail by reducing the post spacings; whereas, the NDR system installs another length of goardrail alongside the face of the guardrail with uniform post spacings of 6 ft-3 in. on centers.

The NDR system has been questioned by some engineers because its performance has not been verified by full-scale crash tests. Therefore, the objective of this study was to conduct a study of "limited" scope using the BARRIER VII computer program to ascertain the cost-effectiveness of the stiff-post system in comparison to the existing NDR double beam system. This study took into consideration the effects of two different size vehicles impacting the guardrail transition area under all possible combinations of impact speed and angle.

The significant findings of this study were as follows:

1. The stiff-post system was not cost-effective because it produced more injury type accidents.
2. The stiff-post system resulted in larger exit angles thereby creating an increased concern of secondary collisions with other vehicles.
3. The stiff-post system produces lower tension forces in the guardrail, and hence, it would perform more effectively if the guardrail to

bridgerail connection could not be made to meet minimum structural requirements. It is not, however, recommended that decreased post spacing be substituted in lieu of a structurally adequate connection because the tension capability in the guardrail is the single most important design element.

The results of this study will be used in the formulation of the NDR guardrail design, installation and maintenance policy. The methodology and procedures developed will be included in the NDR design procedures and will increase the ability of the NDR to evaluate new systems through the cost effective calculations based on BARRIER VII simulations.

Based upon the results of this study there has been shown to be a reasonable doubt as to the cost-effectiveness of the stiff-post system under a wide range of traffic impact conditions. The need is indicated for a more detailed look into the total effectiveness of the stiff-post system. Further research should be conducted to compare the performance characteristics of the two systems by means of full-scale testing and computer model simulations.

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APPENDIX A

BARRIER VII COMPUTER PROGRAM

INPUT DATA: Compact Auto - Stiff Post System

(50 mph/25 deg)

OUTPUT DATA: Interval Time at 260 msec

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***************************************************************************

      RUN ON CORRUGATED STEEL BEAM RAIL _ WOOD POSTS  GUARDRAIL

***************************************************************************


CONTROL INFORMATION

NUMBER OF BARRIER NODES                      =    118
NUMBER OF CONTROL NODES                      =     40
NUMBER OF NODE GENERATIONS                   =     30

NUMBER OF INTERFACES                         =      1

NUMBER OF MEMBERS                            =    157
NUMBER OF MEMBER GENERATIONS                 =      8
NUMBER OF DIFFERENT MEMBER SERIES            =      2

NUMBER  OF ADDITIONAL WEIGHT SETS            =      0


BASIC TIME STEP (SEC)                        =    0.00200
LARGEST ALLOWABLE TIME STEP (SEC)            =    0.10000
MAXIMUM TIME SPECIFIED (SEC)                 =    0.80000
MAX. NO. OF STEPS WITH NO CONTACT            =    100

OVERSHOOT INDEX                              =      0
ROTATIONAL DAMPING MULTIPLIER                =   1.00

STEP-BY-STEP INTEGRATION TYPE                =      1



OUTPUT FREQUENCIES

AUTOMOBILE DATA       =  5
BARRIER DEFLECTIONS   =  5
BARRIER FORCES        = 10

ENERGY BALANCE        = 20

CONTACT INFORMATION   =  5

PUNCHED JOINT DATA    =  0
PUNCHED TRAJECTORY    =  0
```

BEAM ELEMENTS, 100 SERIES

TYPE NUMBER	=	1	2
M. OF I. (IN4)	=	2.310D 00	2.310D 00
AREA (IN2)	=	1.990D 00	1.990D 00
LENGTH (IN)	=	1.875D 01	7.500D 01
YOUNGS MODULUS (KSI)	=	3.000D 04	3.000D 04
WEIGHT (LB/FT)	=	6.820D 00	6.820D 00
YIELD FORCE (K)	=	1.075D 02	1.075D 02
YIELD MOMENT (K.IN)	=	8.880D 01	8.880D 01
YIELD ACCURACY LIMIT	=	1.000D-01	1.000D-01

POSTS, 300 SERIES

TYPE NUMBER	=	1	2	3	4
HEIGHT OF NODE I (IN)	=	2.100D 01	2.100D 01	2.100D 01	2.100D 01
HEIGHT OF NODE J (IN)	=	0.0	0.0	0.0	0.0
A AXIS STIFFNESS (K/IN)	=	1.500D 01	2.200D 00	2.800D 00	1.500D 01
B AXIS STIFFNESS (K/IN)	=	2.200D 00	2.200D 00	2.800D 00	1.500D 01
EFFECTIVE WEIGHT (LB)	=	7.000D 01	7.000D 01	9.000D 01	7.000D 01
B AXIS YIELD MOMENT (K.IN)	=	1.000D 04	2.730D 02	3.465D 02	1.000D 04
A AXIS YIELD MOMENT (K.IN)	=	2.730D 02	2.730D 02	3.465D 02	1.000D 04
YIELD ACCURACY LIMIT	=	1.000D-01	1.000D-01	1.000D-01	1.000D-01
A SHEAR AT FAILURE (K)	=	1.000D 04	1.300D 01	1.650D 01	1.000D 04
B SHEAR AT FAILURE (K)	=	1.040D 01	1.300D 01	1.650D 01	1.000D 04
A DEFLN AT FAILURE (IN)	=	1.000D 04	7.400D 00	7.400D 00	1.000D 04
B DEFLN AT FAILURE (IN)	=	7.400D 00	7.400D 00	7.400D 00	1.000D 04

AUTOMOBILE PROPERTIES

WEIGHT (LB)	=	2250.0
MOMENT OF INERTIA (LB.IN.SEC2)	=	13020.0
NO. OF CONTACT POINTS	=	11
NO. OF UNIT STIFFNESSES	=	1
NO. OF WHEELS	=	4
BRAKE CODE (1=ON, 0=OFF)	=	0
NO. OF OUTPUT POINTS	=	1

UNIT STIFFNESSES (K/IN/IN)

NO.	BEFORE BOTTOMING	AFTER BOTTOMING	UNLOADING	BOTTOMING DISTANCE
1	0.040	0.250	0.330	15.00

CONTACT POINT DATA

POINT	R COORD	S COORD	STIFFNESS NO.	TRIBUTARY LENGTH	INTERFACE CONTACTS			
1	-97.00	-35.00	1	25.00	1	0	0	0
2	-72.00	-35.00	1	25.00	1	0	0	0
3	-48.00	-35.00	1	24.00	1	0	0	0
4	-24.00	-35.00	1	24.00	1	0	0	0
5	0.0	-35.00	1	22.00	1	0	0	0
6	19.00	-35.00	1	19.00	1	0	0	0
7	38.00	-35.00	1	20.00	1	0	0	0
8	58.00	-35.00	1	20.00	1	0	0	0
9	78.00	-35.00	1	19.00	1	0	0	0
10	78.00	-17.50	1	17.50	1	0	0	0
11	78.00	0.0	1	17.50	1	0	0	0

WHEEL COORDINATES (IN), STEER ANGLES (DEG), AND DRAG FORCES (LB)

POINT	R-ORD	S-ORD	STEER ANGLE	DRAG FORCE
1	43.00	27.00	0.0	308.00
2	43.00	-27.00	0.0	308.00
3	-52.00	-27.00	0.0	255.00
4	-52.00	27.00	0.0	255.00

OUTPUT POINT COORDINATES (IN)

POINT	R-ORD	S-ORD
1	0.0	0.0

INITIAL POSITION AND VELOCITIES OF AUTO

SPECIFIED BOUNDARY POINT	=	9
X ORDINATE OF POINT	=	-262.32
Y ORDINATE OF POINT	=	-0.60
ANGLE FROM X AXIS TO R AXIS (DEG)	=	-25.00
VELOCITY IN R DIRECTION (M.P.H)	=	50.00
VELOCITY IN S DIRECTION (M.P.H)	=	0.0
ANGULAR VELOCITY (RAD/SEC)	=	0.0
MINIMUM RESULTANT VELOCITY (M.P.H)	=	5.00
TRANSLATIONAL KINETIC ENERGY (K.IN)	=	2256.99
ROTATIONAL KINETIC ENERGY (K.IN)	=	0.0
TOTAL INITIAL KINETIC ENERGY (K.IN)	=	2256.99

AUTO TRAJECTORY RESULTS

TIME = 0.0 SECS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
1	-318.2	64.1	-25.0	45.32	-21.13	50.00	0.0	50.00	-25.0	0.0	0.0	0.0	0.0	0.0	0.0

BARRIER DEFLECTIONS, TIME = 0.0 SECS

NODE	X-DEFL	Y-DEFL	X-ORD	Y-ORD
1	0.0	0.0	0.0	0.0
2	0.0	0.0	-18.8	0.0
3	0.0	0.0	-37.5	0.0
4	0.0	0.0	-56.3	0.0
5	0.0	0.0	-75.0	0.0
6	0.0	0.0	-93.8	0.0
7	0.0	0.0	-112.5	0.0
8	0.0	0.0	-131.3	0.0
9	0.0	0.0	-150.0	0.0
10	0.0	0.0	-168.8	0.0
11	0.0	0.0	-187.5	0.0
12	0.0	0.0	-206.2	-0.1
13	0.0	0.0	-224.9	-0.2
14	0.0	0.0	-243.6	-0.4
15	0.0	0.0	-262.3	-0.6
16	0.0	0.0	-281.0	-0.8
17	0.0	0.0	-299.8	-1.0
18	0.0	0.0	-318.5	-1.3
19	0.0	0.0	-337.3	-1.6
20	0.0	0.0	-356.0	-1.9
21	0.0	0.0	-374.8	-2.2
22	0.0	0.0	-393.5	-2.6
23	0.0	0.0	-412.2	-2.9

AUTO TRAJECTORY RESULTS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
TIME = 0.2600 SECS															
1	-149.1	38.7	10.0	31.13	5.05	31.54	-0.43	31.54	9.2	-0.47	1.29	-0.24	1.35	1.37	110.0

BARRIER DEFLECTIONS, TIME = 0.2600 SECS

NODE	X-DEFL	Y-DEFL	X-ORD	Y-ORD
1	-0.38	0.01	-0.4	0.0
2	-0.38	0.04	-19.1	0.0
3	-0.38	0.09	-37.9	0.1
4	-0.38	0.14	-56.6	0.1
5	-0.38	0.18	-75.4	0.2
6	-0.39	0.21	-94.1	0.2
7	-0.39	0.18	-112.9	0.2
8	-0.39	-0.57	-131.6	-0.6
9	-0.37	-1.51	-150.4	-1.5
10	-0.16	-4.42	-168.9	-4.4
11	-0.01	-6.92	-187.5	-6.9
12	0.03	-8.36	-206.2	-8.5
13	0.01	-8.48	-224.9	-8.7
14	0.00	-7.81	-243.6	-8.2
15	0.08	-5.77	-262.2	-6.4
16	0.17	-3.68	-280.9	-4.5
17	0.25	-1.63	-299.5	-2.6
18	0.24	-1.10	-318.3	-2.4
19	0.24	-0.71	-337.0	-2.3
20	0.23	-0.42	-355.8	-2.3
21	0.22	-0.22	-374.5	-2.4
22	0.22	-0.09	-393.3	-2.6
23	0.22	-0.01	-412.0	-3.0
24	0.21	0.02	-430.7	-3.3
25	0.21	0.04	-449.4	-3.7
26	0.21	0.04	-468.2	-4.2
27	0.20	0.03	-486.9	-4.8
28	0.20	0.02	-505.6	-5.3
29	0.20	0.00	-524.3	-5.9
30	0.20	-0.01	-543.0	-6.5
31	0.19	-0.02	-561.7	-7.2
32	0.19	-0.02	-580.4	-7.8
33	0.19	-0.03	-599.1	-8.4
34	0.19	-0.02	-617.8	-9.2
35	0.18	-0.02	-636.5	-10.0
36	0.18	-0.02	-655.3	-10.8
37	0.18	-0.01	-674.0	-11.5
38	0.18	-0.01	-692.7	-12.4
39	0.18	-0.01	-711.4	-13.3

MEMBER FORCES, TIME = 0.2600 SECS

BEAMS, 100 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	I-MOMENT	J-MOMENT	F-CODE	M-CODE
1	1	2	101	5.53	0.00	1.07	1	1
2	2	3	101	5.52	-1.07	1.66	1	1
3	3	4	101	6.45	-1.66	-0.46	1	1
4	4	5	101	6.44	0.46	-3.75	1	1
5	5	6	101	7.38	3.75	-10.23	1	1
6	6	7	101	7.37	10.23	-18.30	1	1
7	7	8	101	8.31	18.30	-36.02	1	1
8	8	9	101	8.29	36.02	-56.22	1	1
9	9	10	101	9.35	56.22	-37.36	1	1
10	10	11	101	9.29	37.36	-14.00	1	1
11	11	12	101	9.09	14.00	5.59	1	1
12	12	13	101	8.98	-5.59	38.79	1	1
13	13	14	101	9.44	-38.79	34.48	1	1
14	14	15	101	10.19	-34.48	13.00	1	1
15	15	16	101	10.20	-13.00	-10.28	1	1
16	16	17	101	10.20	10.28	-36.96	1	1
17	17	18	101	9.43	36.96	-26.56	1	1
18	18	19	101	9.43	26.56	-20.04	1	1
19	19	20	101	9.43	20.04	-16.46	1	1
20	20	21	101	9.42	16.46	-15.11	1	1
21	21	22	101	8.92	15.11	-10.69	1	1
22	22	23	101	8.91	10.69	-7.35	1	1
23	23	24	101	8.91	7.35	-4.64	1	1
24	24	25	101	8.91	4.64	-2.20	1	1
25	25	26	101	8.43	2.20	-1.55	1	1
26	26	27	101	8.42	1.55	-0.88	1	1
27	27	28	101	8.42	0.88	-0.21	1	1
28	28	29	101	8.42	0.21	0.44	1	1
29	29	30	101	7.96	-0.44	0.57	1	1
30	30	31	101	7.95	-0.57	0.66	1	1
31	31	32	101	7.95	-0.66	0.70	1	1
32	32	33	101	7.95	-0.70	0.72	1	1
33	33	34	101	7.50	-0.72	0.42	1	1
34	34	35	101	7.50	-0.42	0.14	1	1
35	35	36	101	7.50	-0.14	-0.11	1	1
36	36	37	101	7.49	0.11	-0.34	1	1
37	37	38	101	7.07	0.34	-0.27	1	1
38	38	39	101	7.07	0.27	-0.19	1	1
39	39	40	101	7.06	0.19	-0.10	1	1
40	40	41	101	7.06	0.10	-0.02	1	1
41	41	42	101	6.66	0.02	0.02	1	1

POSTS, 300 SERIES

MEMBER	NODE I	NODE J	TYPE	A-SHEAR	B-SHEAR	B-MOMENT	A-MOMENT	CODE
118	1	0	304	-5.63	0.09	-118.19	1.85	1
119	3	0	303	-1.06	0.25	-22.29	5.18	1
120	5	0	303	-1.07	0.52	-22.57	10.84	1
121	7	0	303	-1.10	0.51	-23.07	10.61	1
122	9	0	302	-0.82	-3.32	-17.15	-69.74	1
123	11	0	302	0.0	0.0	0.0	0.0	0
124	13	0	302	0.0	0.0	0.0	0.0	0
125	17	0	302	0.55	-3.59	11.48	-75.44	1
126	21	0	302	0.49	-0.48	10.38	-9.99	1
127	25	0	302	0.46	0.08	9.64	1.67	1
128	29	0	302	0.44	0.01	9.19	0.11	1
129	33	0	302	0.42	-0.06	8.77	-1.17	1
130	37	0	302	0.40	-0.03	8.31	-0.57	1
131	41	0	302	0.38	-0.02	7.90	-0.45	1
132	45	0	302	0.36	-0.03	7.51	-0.53	1
133	49	0	302	0.34	-0.02	7.14	-0.44	1
134	53	0	302	0.32	-0.02	6.80	-0.35	1
135	57	0	302	0.31	-0.01	6.47	-0.27	1
136	61	0	302	0.29	-0.01	6.16	-0.17	1
137	65	0	302	0.28	-0.01	5.88	-0.22	1
138	69	0	302	0.27	-0.01	5.61	-0.12	1
139	73	0	302	0.26	-0.01	5.36	-0.13	1
140	77	0	302	0.24	-0.00	5.12	-0.01	1
141	81	0	302	0.23	0.00	4.90	0.01	1
142	85	0	302	0.22	0.00	4.70	0.02	1
143	89	0	302	0.21	0.00	4.51	0.07	1
144	93	0	302	0.21	0.01	4.33	0.13	1
145	97	0	302	0.20	0.00	4.17	0.10	1
146	101	0	302	0.19	0.01	4.02	0.15	1
147	105	0	302	0.18	0.01	3.88	0.16	1
148	109	0	302	0.18	0.01	3.74	0.23	1
149	110	0	302	0.17	0.01	3.62	0.24	1
150	111	0	302	0.17	0.01	3.51	0.27	1
151	112	0	302	0.16	0.02	3.40	0.33	1
152	113	0	302	0.16	0.02	3.30	0.39	1
153	114	0	302	0.15	0.01	3.25	0.26	1
154	115	0	302	0.15	-0.00	3.23	-0.01	1
155	116	0	302	0.15	0.02	3.06	0.52	1
156	117	0	302	0.13	0.08	2.77	1.66	1
157	118	0	301	0.78	0.15	16.32	3.22	1