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16. Abstract

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EVALUATION OF THE HIGH LOAD DETECTION AND WARNING SYSTEM ON I.H. 45 IN HOUSTON

by

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Research Report Number 202-1

Design and Evaluation of Freeway Surveillance
and Traffic Control Systems

Research Study Number 2-18-75-202

Sponsored by
The State Department of Highways and Public Transportation
In Cooperation with the
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Federal Highway Administration

Texas Transportation Institute
Texas A&M University
College Station, Texas

March 1976

ABSTRACT

The detection and warning system to alert truck drivers of over-height loads in advance of a low clearance structure on I.H. 45 in Houston is evaluated. Volume and speed data taken during control studies indicate that the warning system did not adversely affect traffic operations in the study section. Analysis of brake light applications indicate that in three of five time periods over three days, the warning system was significantly noticeable and did cause monentary braking reactions. Tests conducted on the photoelectric sensors and incandescent lamp source in the detection system indicate that various size objects (one inch and more in size) will be detected under certain light source to detector distances.

Key Words: Photoelectric Detection, Structure Damage, Equipment Test, Freeway Operations, High Load Warning Devices

DISCLAIMER

SUMMARY

An Overheight Load Detection and Warning System was implemented by District 12 of the State Department of Highways and Public Transportation on I.H. 45 near the I.H. 10 exit just north of the Houston Central Business District. The system was to function by detecting objects passing through a continuous light beam 14 feet (4.3 meters) above and transverse to the northbound I.H. 45 roadway and actuating a series of amber flashing lamps on the static message signs in advance of the Hogan Street overpass. The static messages advised drivers with overheight loads to divert to the westbound I.H. 10 roadway.

The objectives of the study were to determine:

1) The effects of the flashing amber warning system on traffic in the study site area;
2) The sensitivity of the detection system; and
3) The effectiveness of the total system in protecting the Hogan Street overpass from being damaged.

Control studies were implemented at the study site to determine the effects of the warning system on traffic. Traffic data in the form of volumes, speeds, and the frequency of brake light applications were collected during the five time periods over three days. Each of the 11 studies for each time period was composed of three minutes of data taken 1) immediately before the warning system was manually activated, 2) while the warning system's lamps were flashing, and 3) immediately after the warning system had ceased operations. Analysis of the volume and speed data indicated that the operations of the warning system did not adversely affect the normal traffic operations in the study section. The brake

light data analysis did show that the system was noticeable by the driver in three of the five time periods over the three-day period. During the control studies, only one overheight load was observed using the I.H. 45 roadway. The driver entered the study site while the warning system was operating and diverted to the I.H. 10 westbound exit.

Identical units to those employed in the detection system at the study site were used in measuring the sensitivity of the detection device. Two photoelectric sensors were installed side-by-side 8 inches (20.3 centimeters) apart and the circuits wired so that shadows of objects passing in only one direction across the sensors could be detected. Test results indicated that objects must pass through the detection zone at speeds greater than 2 MPH (3 kilometers per hour) and less than 450 MPH (720 KPH) for detection to occur. The incandescent light source acts as a point source, and consequently, light diffraction around an object determines at what maximum distance from the sensors an object may be detected. By varying the distance between the light source and the detector from 40 feet (12 meters) to 90 feet (27 meters), the following test data were collected which determined the maximum distance from the sensor that an object passing through the detection zone may be detected:

1) One-inch (2.5 centimeters) object out to 20 feet (6 meters);
2) Two-inch (5 centimeters) object out to 55 feet (16 meters);
3) Three-inch (7.5 centimeters) object out to 70 feet (21 meters); and
4) Five-inch (12.7 centimeters) object out to 80 feet (24 meters).

Objects closer than five feet (1.5 meters) to the light cource caused shadow speeds across the sensors to be much greater than the object speed. In fact, objects passing in front of the light source closer than five feet and passing across the detection zone at 50 MPH (80 kilometers per hour) caused images to pass across the sensors at speeds greater than 500 MPH (800 kilometers per hour). Shadow speeds greater than 450 MPH (720 KPH) are not detected due to the limitations of the electronic circuitry. Further testing revealed that exhaust smoke and radio antennas were non-detectable.

During the control studies, only one overheight load was observed to use the I.H. 45 northbound roadway. The warning system was already operating when the vehicle entered the study section. The driver did divert to the I.H. 10 exit ramp as directed by the messages. Also, the author observed one other overheight load, at a later time, that was detected. The driver did divert to the I.H. 10 westbound roadway. There is evidence that the detection and warning system is not totally successful in sensing and diverting all overheight loads. District 12 forces welded steel plates to the downstream most portion of the exposed steel girders of the Hogan Street structure. Periodic inspections of the surface of the steel plates indicate scratches and skid marks. Also, the low clearance signs on the upstream face of the structure have been damaged. Attempts were made to determine if the detection and warning system had been in operation when these high loads struck the structure. A counter in the warning system's controller was designed to operate each time an overheight load was detected. However, observations of the counter indicated it was malfunctioning by overcounting. Modifications to the counter circuitry have not completely corrected the problem and a direct correspondence between the low clearance sign damage or the steel plates being scratched and recorded actuations of the warning system was not possible. An inspection of the skid marks on the surface of the steel plates revealed that the majority of the marks were made by booms. The booms may have been missed due to the limitations of the detection or to the bouncing effect caused by the undulating road surface.

Even though conclusive results on the effectiveness of the warning system to divert overheight loads were not obtainable within the scope of this study, there is evidence that the detection and warning system does provide a measure of advance warning to the traffic approaching Hogan Street overpass. Further, it was indicated by this study that this advanced warning system was not detrimental to the operation of the freeway.

Recommendations for Implementation

The Hogan Street overpass on I.H. 45 in Houston is one of several bridge structures inside the I.H. 610 Loop where vertical clearances of 15 feet (4.5 meters) or less exist. Other regions within the State of Texas, while not reporting excessive bridge damage figures from overheight loads, do have structures which sustain infrequent damages. The utilization of a detection and warning system will enable the majority of drivers with overheight loads to be warned in advance of a low clearance structure. While the warning system requires a voluntary reaction from the drivers of overheight loads, the total system does provide a measure of advance warning and protection to low clearance structures and is not detrimental to the operation of the freeway.

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Statement of the Problem

Damages to the superstructures of bridges caused by collision with overheight loads being transported by trucks is not considered a major state-wide problem. Of the $141,000,000 allocated in the 1974-75 State Department of Highways and Public Transportation (SDHPT) budget, it has been estimated by SDHPT officials that approximately $500,000 or 0.35 percent of the total budget was spent on bridge repairs damaged by overheight loads. District 12 of the SDHPT, encompassing the greater Houston area, experiences an average of twenty-four damaged structures each year and accounts for one-third of the total state-wide expenditures for bridge repairs. The cost of repairs for each bridge averages from $8,000 to $15,000. The District is reimbursed by the party at fault only if the party is 1) known and lawfully sued for damages or 2) voluntarily contacts the District for insurance coverage payment.

Figures 1 through 3 indicate the typical damages sustained within the District. Figure 1 is a photograph of one of two former structures on Loop 137 over U.S. 59 northeast of the Houston Central Business District (CBD). The overheight load damaged all I-beams under the northernmost structure with the last two beams severely damaged. The entire structure would have had to be replaced, at a cost of approximately $200,000, except this overpass structure was scheduled for replacement. The posted road clearance was 14 feet and 0 inches. Figure 2 is the Houston Avenue Overpass on the I.H. 10 eastbound near the Houston CBD. The posted road clearance of 14 feet and 2 inches on

FIGURE 1. WESTBOUND LOOP 137

BRIDGE OVER U.S. 59 SOUTHBOUND

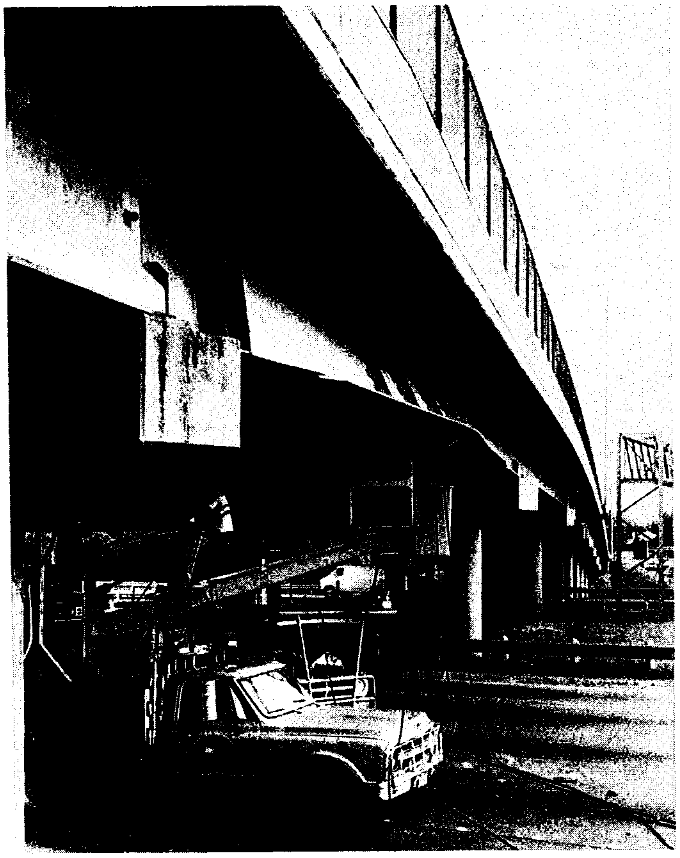

FIGURE 2. HOUSTON AVENUE OVERPASS ON

I.H. 10 EASTBOUND

FIGURE 3. ROBINSON ROAD OVERPASS ON I.H. 45 NORTHBOUND IN MONTGOMERY COUNTY

this structure did not prevent an overheight load from attempting to pass under the structure. The load raked all I-beams under the structure, but the most severely damaged was the last beam. The entire beam and a portion of the outer slab had to be replaced at a cost of $68,000. Figure 3 denotes the damage sustained by the first prestressed concrete beam on a posted 14 feet and 11-inch structure on I.H. 45 in Montgomery County at the Robinson Road Overpass. The damaged I-beam is scheduled to be repaired at an estimated cost of $12,000. In all but the last case, the District was reimbursed for part or all of the cost for replacement.

Figure 4 indicates the damage sustained by an overheight sign bridge structure on I.H. 45 southbound at the Cavalcade exit near the Houston CBD. Although the sign structures are not damaged as frequently as bridge superstructures, repairs are likely to be more costly. The road clearance was 17 feet 6 inches. A truck pulling a dump trailer with a malfunctioning dump mechanism which in turn was raising the trailer struck the sign structure. Replacement cost for the sign structure was $35,000. Figure 4, along with the previous 3 figures, indicates the general damages sustained by the structures in District 12.

Several different factors contribute to the problems of overheight loads damaging roadway structures in the Greater Houston Area:

- The Greater Houston Metropolitan Area depends, for the most part, on the use of freeways for private, commercial, and public transportation. This is supported by the fact that of the more than 215,500,000-vehicle miles of travel estimated in the State of Texas in 1974, more than 18 percent was driven in District 12. Harris County had over 1,420,900 total vehicle registrations in 1974 (15 percent of the

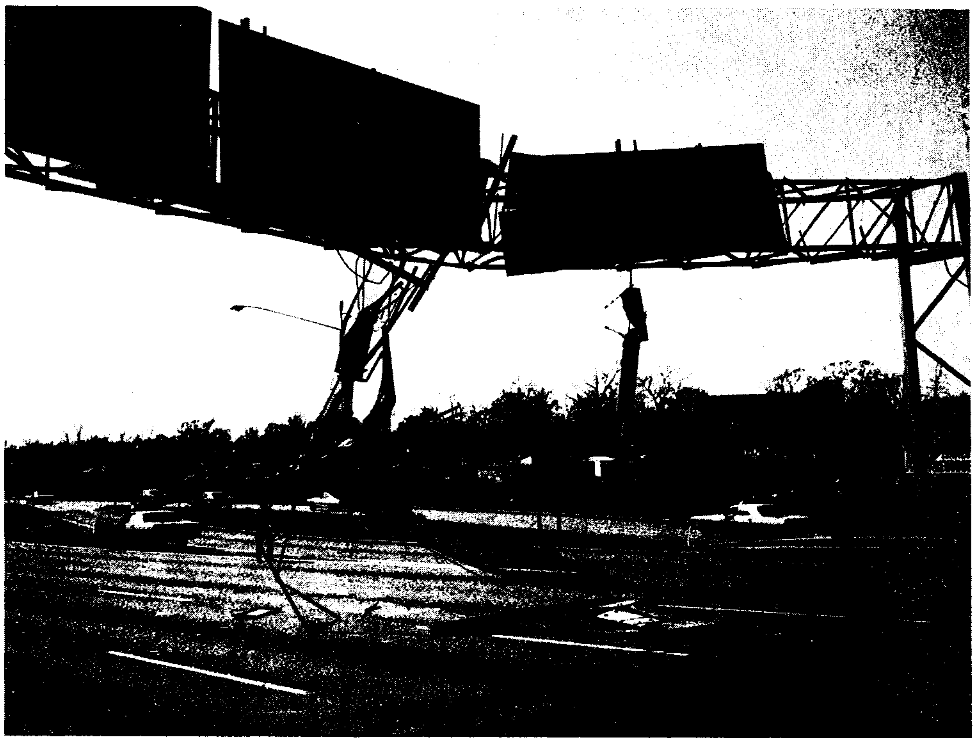

FIGURE 4. OVERHEAD SIGN BRIDGE STRUCTURE

ON I.H. 45 SOUTHBOUND AT THE CAVALCADE STREET EXIT state total)[1]. Over 30 percent of the total Harris County vehicle registrations were non-passenger types (trucks, tractors, trailers, etc.).

·The Greater Houston Metropolitan Area supports state-wide and national leaders in chemical, petroleum, and allied products; primary and fabricated metal products; and oilfield machinery production. To serve the third largest seaport in the United State, six major rail systems and over 100 regulated trucking firms moved almost 84 million tons of cargo in 1974[2]. Also, a rapidly developing population gives rise to large scale housing and business construction.

·The freeway system, as it is in Houston, is a series of interconnecting limited access (and egress) roadways which, near the downtown Houston area, do not have accompanying frontage roads. Vehicles, once on a roadway, may have only a limited number of alernative routes before arriving at a low clearance obstacle.

·Trucking firms are sometimes negligent in securing permits, routes, or the instruction of drivers which often results in structural roadway damage by overheight loads.

·Drivers' disinterest in road heights or ignorance about low clearance problems on a roadway, load type, and bouncing loads caused by maintaining freeway speeds and undulating roadway surfaces also attributes to the structural roadway damage.

Objectives

The objectives of the study were to determine:

1) The effects of the warning system on traffic in the study site;
2) The sensitivity of the detection system; and
3) The effectiveness of the system in protecting the Hogan Street overpass from being damaged.

Description of the Study Site

As indicated in Figure 5, the study site is located immediately North of the Houston downtown area on the I.H. 45 northbound lanes. I.H. 45 northbound traffic, once past U.S. 59 and several downtown exits, must proceed through the detection and warning system. Traffic moving north out of the downtown area, has only two major freeway routes to follow: U.S. 59 and I.H. 45. The overheight load detector is located, as depicted in Figure 6, on the overheight bridge structure connecting I.H. 10 westbound traffic to I.H. 45 southbound traffic. The detection system consists of an incandescent light source, Figure 7, and a photoelectric detector, Figure 8. The light source is mounted on the west side of I.H. 45 and the photoelectric detector is mounted on the east side. The detection devices are mounted such that the detection zone, 14 feet (4.1 meters) from the pavement surface, is perpendicular to the direction of freeway traffic flow. The I.H. 45 roadway is four lanes wide (12 feet, 3.6 meters, each lane) with an emergency lane (10 feet, 3.0 meters) on each side of the detection station. The lateral clearance of each component of the detection system averages 5 feet (1.5 meters). It is estimated that 78 feet (23.8 meters) separate the light source and photoelectric detector. Both units are powered by normal AC voltages.

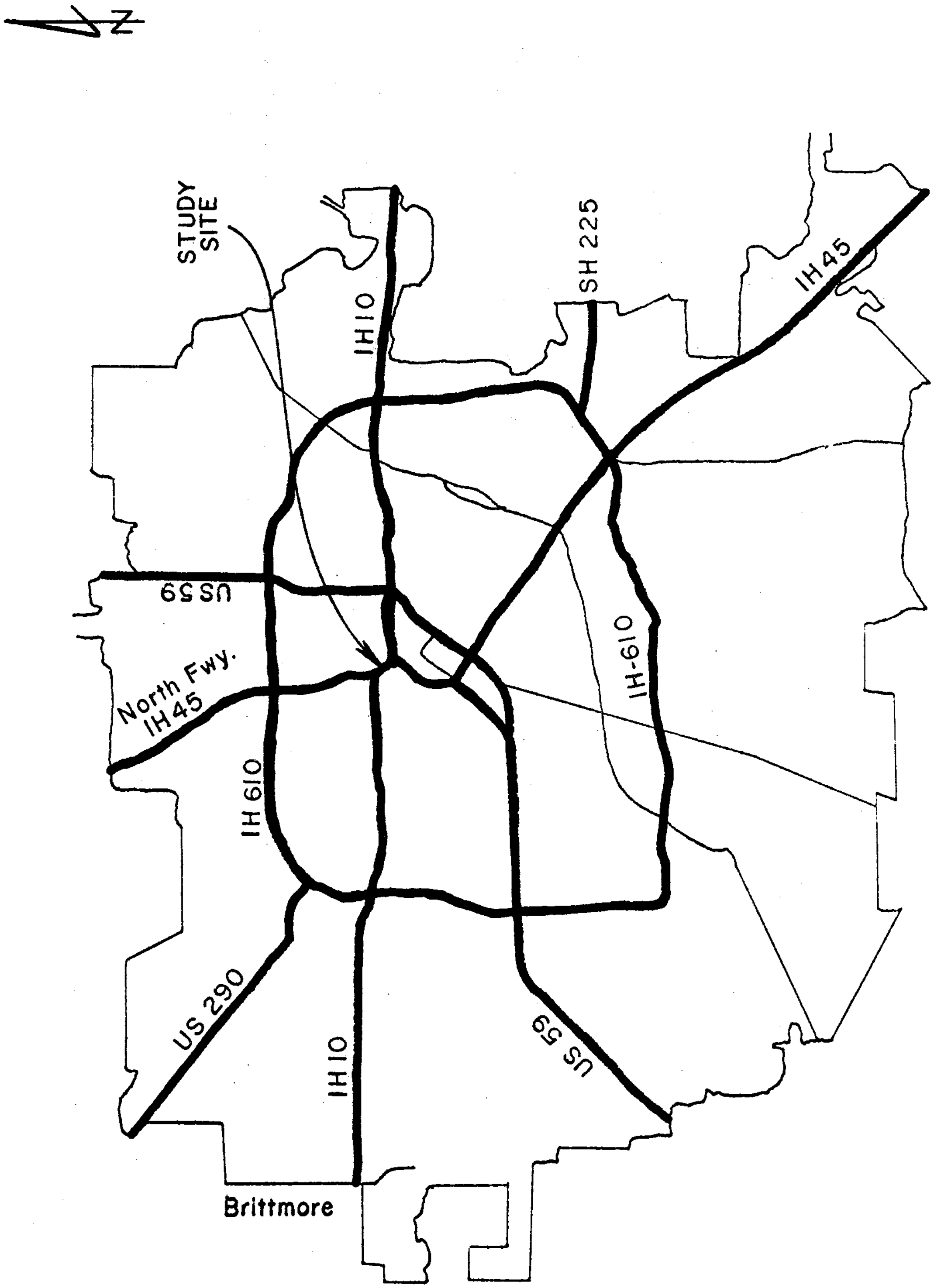

FIGURE 5. HOUSTON AREA FREEWAY SYSTEM

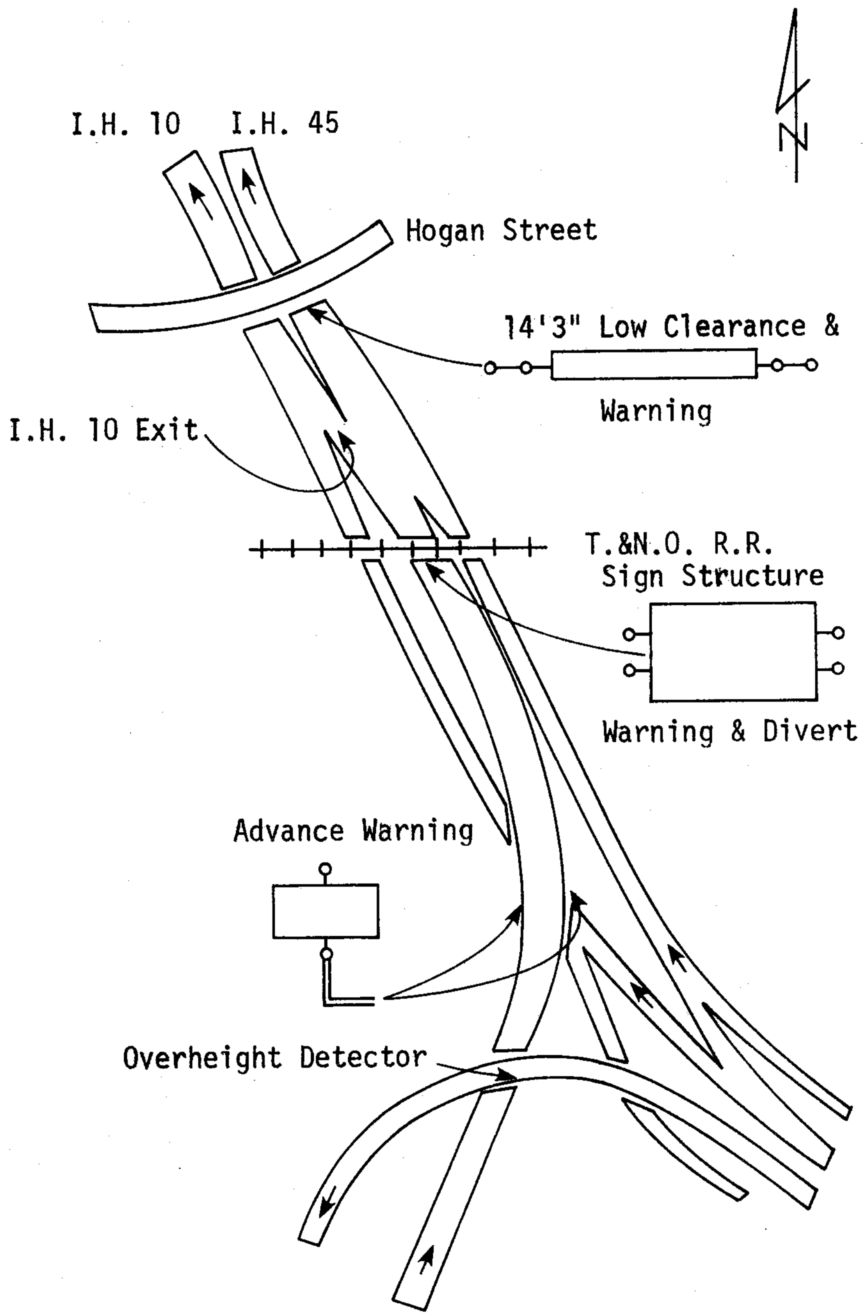

FIGURE 6. OVERHEIGHT LOAD DETECTION AND WARNING SYSTEM STUDY SITE

FIGURE 7. DETECTOR LIGHT SOURCE

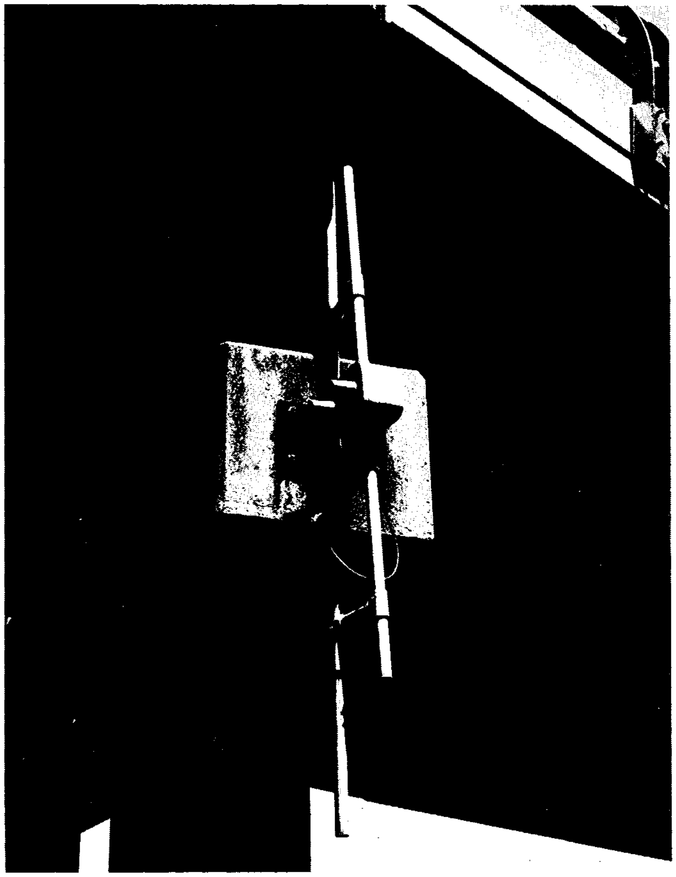

FIGURE 8. SENSOR INSTALLATION

Once an object has been detected as passing through the detection zone, a relay closure in the photoelectric device causes 117 AC voltage to be passed to the warning system controller. The controller is mounted to the overhead bridge sign structure prior to the T&NO Railroad bridge. The AC voltage enables a manually adjustable decade timing circuit to immediately activate the four separate flashing devices. Two rectangular warning signs and flashers (Figure 9), one mounted to each side of the roadway approximately 1,200 feet (365.8 meters) in advance of the I.H. 10 exit, are activated. Another warning sign with flashers is mounted on the west side of the overhead sign bridge structure (Figure 10). The final warning sign and signal lamps are mounted to the Hogan Street structure as shown in Figure 11. All amber flashers operate for a selected interval of time. The variable interval of time, as discussed in later paragraphs, is approximately 2.5 minutes in duration. Initially, the warning system controller contains a counter which records the number of detection system actuations. The total distance from detection station to the Hogan Street structure is approximately 1,700 feet (518.2 meters) with the I.H. 10 exit ramp 500 feet (150 meters) upstream of the overpass.

Method of Study

The ideal concept to evaluate the Overheight Load Detection and Warning System would be to observe or record each and every load which did and did not activate the system. Consideration was given to relocating the mobile microwave television system currently in use on the Gulf Freeway to the study site. This type of monitoring would have required extensive modification to the TV camera support, be costly to relocate, require office space or a special trailer somewhere near the study site for the TV monitor and recorder, and require continuous manual observation to enable the

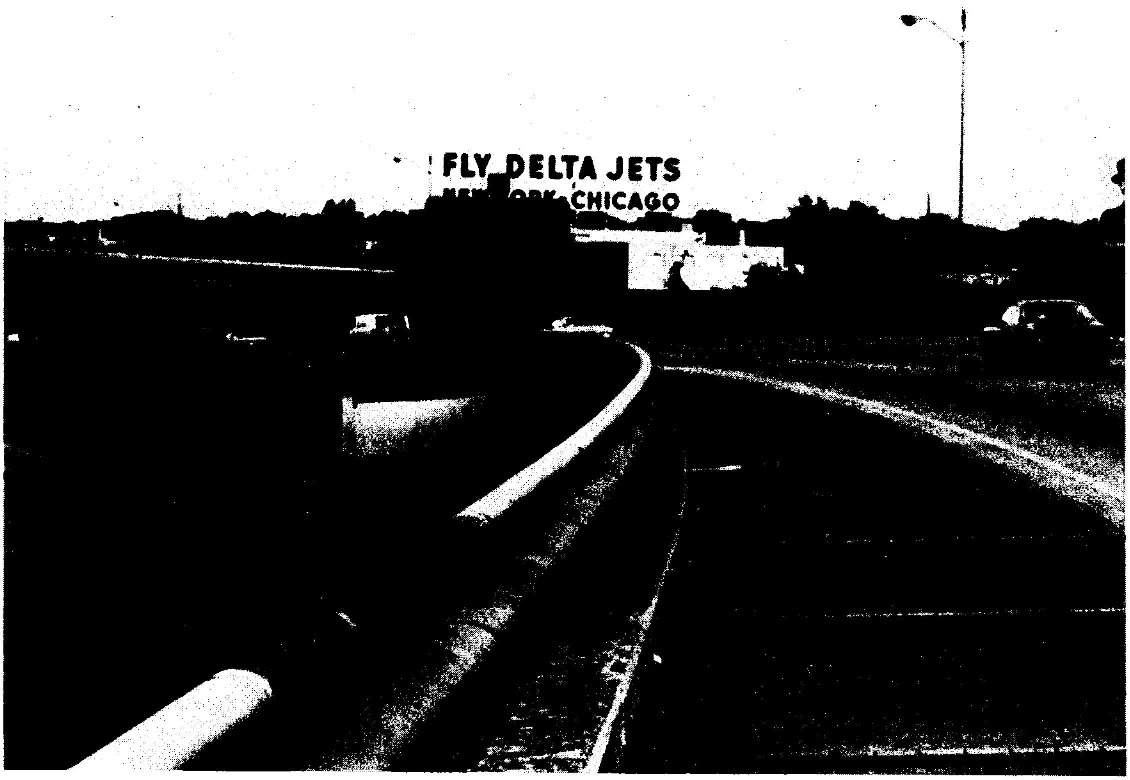

FIGURE 9. ADVANCE WARNING SIGN

FIGURE 10. DIVERT SIGN INSTALLATION

FIGURE 11. SIGNING AT LOW CLEARANCE STRUCTURE

recording of traffic conditions during an actuation.

Another method which was considered was to record the traffic operations on photographic film. Recording equipment normally used in traffic studies by TTI was considered. The only available cameras used 16-mm film. Because of the indiscriminant activation of the detection system (as described in subsequent paragraphs), 16-mm film and film processing was determined to be too expensive for use in this particular situation. The possibility of a large quantity of film being used due to the apparent large quantity of false actuations required the equipment and supplies be relatively inexpensive. The possibility of the recording equipment being damaged was also a consideration in eliminating the use of 16-mm film. These factors supported the consideration of utilizing 8-mm equipment.

Four widely marketed 8-mm film types, commonly used by the general public, were obtained with an inexpensive 8-mm camera secured on temporary loan from a local photographic equipment supplier. Film tests were conducted during the daylight and nighttime periods on each of the four film types. The camera had the option of exposing film at 18 frames per second (normal speed) and 9 frames per second (half speed). The filming time for each 50-foot roll of 8-mm film, exposed at normal speed would record 3 minutes and 20 seconds of traffic operations. Filming at half speed would enable 6 minutes and 40 seconds of data to be recorded. Some difficulty was encountered in selecting a single vantage point where the entire study section would be recorded. Two locations were used; directly above the detection station on the I.H. 10 west to I.H. 45 south structure filming traffic moving into the I.H. 10 west exit area and on the Hogan Street overpass directly above the north I.H. 45 freeway lanes filming oncoming traffic at the I.H. 10 west exit. Table 1 indicates the results of the film analysis.

Each film type, after processing, was analyzed for: 1) ability of individual vehicles to be distinguished (definition), 2) clarity of images, 3) visibility of brake light applications and 4) variability of film exposure latitudes between the daytime and nighttime lighting conditions. Each film was exposed at half speed as well as normal speed. The Ektachrome color film was judged to produce the most acceptable images for traffic data analysis even at half speed. The analysis also indicated that 1) a single camera mounted above the I.H. 45 roadway at the detection station could be used if the camera had a zoom lens capability or 2) two cameras would have to be used because of the inability to adequately distinguish vehicle maneuvering at the I.H. 10 west exit utilizing similar lenses to that of the test camera if used at a single vantage location. Surveying the local photography suppliers indicated that 8-mm cameras with half speed filming capabilities, adaptibility for remote control, automatic light compensation, and the proper zoom lens selection would no longer be economical. Further investigation indicated problems in securing the proper environmental housings, vibration-dampening mounting adaptors, remote electrical power, and warning system interconnections as well as the possibility of theft or damage to the equipment once installed at the study site. After carefully reviewing the objectives of the study, the available resources, the probable traffic results obtainable from the 8-mm film, and the added equipment costs, the decision was made not to further investigate the utilization of photographic recordings of the traffic operations.

Repeated daily visits to the warning system controller cabinet indicated numerous actuations being recorded each day. Therefore, the study site was

TABLE 1. 8-MM Film Test Results

TIME/FILMING SPEED	COLOR FILMS		BLACK/WHITE FILMS	
	Kodachrome ASA 25	Ektachrome ASA 160	Tri-X ASA 280	Plus-X ASA 80
Day/18 fps	Good color and definition	Good color and definition	Slight over exposure, no brake lights observed	No brake lights, good exposure and definition
Day/9 fps	Good color and definition, but jumpy	Good color, grainy, slightly over exposure, and jumpy cars	Over exposed jumpy, no brake lights	Good exposure and definition, but no brake lights
Night/18 fps	Under exposurer, no lane definition and only tail lights	Good color and good definition	Grainy, good exposure and definition	Under exposed, only brake lights
Night/9 fps	Under exposurer, little definition, and jumpy	Good color, grainy, jumpy, less definition than 18 fps	Same as 18 fps but very grainy	Under exposed, see only head lights

manually observed for several periods throughout the day for several days but no overheight load was observed using the study area. The controller, upon being visited each early AM and late PM period of the day, still indicated a large number of actuations of the detection system. Further investigation into the electrical circuitry of the controller indicated several possible problem areas. Several changes to the controller were suggested to District 12 and the changes were made. Documentation of the controller changes and actuation recordings are included in the study results.

Two study techniques were used in the final evaluation of the Overheight Load Detection and Warning System. The effects of the warning system operations on traffic and the accuracy of the detection system were analyzed. Traffic data in the form of brake light applications, spot speeds, and one-minute traffic volumes were manually taken during five different periods each day for three days. A total of 55 studies were conducted and only one overheight load was observed using the study area during the three-day test period. The accuracy of the detection system was conducted by using similar units to that installed on I.H. 45 in a controlled test. Several interesting facts were discovered concerning the minimum width of an object for detection, the speed at which an object passes through the light beam, and the distance an object is from both the light source and the photoelectric detector for detection to occur. Complete test results are given in the Study Results paragraphs.

STUDY RESULTS

Effect of Warning System on Traffic

Traffic data were taken at five different time periods of the day for three days. The time periods were selected to provide a wide variation in vehicles and drivers for sampling. The starting time of each period is indicated in Table 2 and was normally extended for one hour. Each study consisted of three sets of data and each data set was composed of three one-minute data values. The data sets were differentiated according to the manual activation of the warning system; three minutes of data immediately before the activation of the flashers, three minutes of data with the flashers operating, and three minutes of data immediately after the flashers ceased operations. During each of the three-minute time periods, multiple studies were conducted until the period expired.

Two separate sets of volume data were taken each minute; the three-lane volume using I.H. 45 north under Hogan Street, and the exiting two-lane volume using the I.H. 10 west exit from I.H. 45 north. Speed data were manually taken by stopwatch over a 500-foot speed trap that ended at the overhead bridge sign structure. Brake light actuations were observed from above the detection station on the overhead I.H. 10 west to I.H. 45 south connection. Also, an audio cassete recording was made by an observer documenting any significant events that might have occurred during the study. All traffic data were transposed to computer cards and analysis programs were coded for operations in the IBM digital computer at the Gulf Freeway Surveillance Control Center.

The studies were sequentially numbered and control codes inserted on the data cards. This enabled the analysis programs to group together

TABLE 2. Study Period Time Assignments

STUDY PERIOD	START TIME
Period 1 AM Off Peak	9:30 AM
Period 2 Noon	12:00 PM
Period 3 PM Off Peak	2:30 PM
Period 4 PM Peak	5:30 PM
Period 5 Night	9:00 PM

all data sets by time periods of the day. Separate programs analyzed volumes, speeds, and brake light application data.

In the analysis of the speed data (Table 3), more than 4,400 vehicles in the 15 separate data sets were used. Average sample size was 294 vehicle speeds. The mean speed for all time periods of the day indicates that traffic operations in the study section remained stable even with the warning system operating. The one-or two-mile per hour variations in the mean speeds when the warning system was operational as opposed to non-operation was analyzed for significance. A Student's t distribution function was used with the hypothesis that the means were unequal and that the populations were significantly different. In comparing the before-to-during, during-to-after, and before-after (Table 7), any t value greater than 1.96 would indicate the hypothesis is true and the difference in means is significant at the 5 percent level. No t value approached the 1.96 factor. Therefore, the warning system operations did not significantly affect the mean traffic speeds at the study site.

Volume data were analyzed by finding the mean one-minute flow rate for the 3-lane and 2-lane directions as well as combining the two data sets for a combined one-minute volume. Again, the difference in means was checked for significance at the 5 percent confidence level (Table 8). No significance can be placed on the variations of the mean one-minute flow rates, therefore the warning system operation could not be responsible for the variation in the traffic volumes at the study site.

Analysis of the brake light applications (Table 9) was structured the same as was the analysis of volume and speed data. The significance test (Table 10) indicates that the traffic in Periods 2 (Noontime), 4 (PM peak), and 5 (Nighttime) was affected by the warning system operations. The audio observations indicated that during Period 2 a funeral procession came through the study area while the system was operating. Also, during a nighttime study an overheight load had to divert causing virtually every vehicle that used the freeway to come to a stop. Period 4 is in the afternoon peak traffic period. The overall increase in the number of brake light applications is due in part to the merging of the exiting I.H. 45 traffic onto I.H. 10 west lanes. In general, more brake lights were momentarily applied just prior to or adjacent to the first warning sign which is in advance of the beginning of the speed trap. Particular care was exercised, whenever possible, not to activate the warning system if a large truck was immediately in advance of the large overhead sign. Even when trucks were present and the warning system was activated, there did not appear to be any panic braking occurring. The analysis of the brake light application indicated that the system does affect traffic in that drivers do have a tendency to temporarily apply their brakes while not affecting their overall speed.

Summary of Effects of Warning System

Traffic data taken under controlled conditions at the study site on I.H. 45 revealed that 1) flow rates through the system do not significantly change when the warning system is operating, 2) no significant speed reductions occur when the warning system is operational, and 3) drivers have a greater tendency to temporarily apply a braking action when the system is operational than when it is not.

Overheight Load Detector Accuracy

The overheight load detector system, as currently in use, is composed of an incandescent light source and a photoelectric cell detector. Both units are enclosed in separate cast aluminum environmental housing and

TABLE 3. Speed Data Analysis Results

STUDIES		SAMPLE SIZE	MEAN	STANDARD DEVIATION	VARIANCE
Period 1	Before	287	52.59	5.55	30.70
	During	260	52.33	5.90	34.70
	After	290	53.11	5.75	33.03
Period 2	Before	301	54.44	6.05	36.49
	During	286	52.98	5.71	32.57
	After	3.6	53.98	5.90	34.73
Period 3	Before	302	52.42	6.01	36.09
	During	297	51.77	5.18	26.75
	After	310	53.35	5.70	32.40
Period 4	Before	305	52.69	5.29	27.99
	During	295	52.68	5.25	27.51
	After	313	52.81	5.26	27.58
Period 5	Before	298	53.53	6.02	36.12
	During	263	51.53	7.01	49.03
	After	296	54.04	5.58	31.12

(To convert from MPH to KMPH multiply by 1.61).

TABLE 4. Three-Lane Volume Data Analysis Results

STUDIES		MEAN	STANDARD DEVIATIONS	VARIANCES
Period 1	Before	26.79	6.46	40.47
	During	24.76	7.18	50.00
	After	26.73	6.15	36.62
Period 2	Before	31.97	7.54	55.06
	During	30.88	8.90	76.77
	After	30.45	7.13	49.28
Period 3	Before	42.79	9.47	86.95
	During	41.97	7.95	61.24
	After	45.15	10.44	105.64
Period 4	Before	50.09	7.95	61.23
	During	50.15	5.88	33.58
	After	48.21	8.52	70.47
Period 5	Before	22.97	5.86	33.30
	During	22.30	7.08	48.57
	After	22.45	5.86	33.34

TABLE 5. Two-Lane Volume Data Analysis Results

STUDIES		MEAN	STANDARD DEVIATIONS	VARIANCES
Period 1	Before	13.70	3.60	12.57
	During	13.30	3.30	10.57
	After	13.42	3.79	13.94
Period 2	Before	16.09	4.98	24.08
	During	15.79	6.23	37.68
	After	16.30	7.37	52.70
Period 3	Before	21.42	4.97	23.94
	During	22.73	4.85	22.80
	After	22.36	4.07	16.05
Period 4	Before	28.97	6.24	37.73
	During	30.76	5.04	24.61
	After	29.48	5.05	24.73
Period 5	Before	10.55	3.77	13.76
	During	10.94	3.87	14.54
	After	11.48	3.99	15.46

TABLE 6. Combined Volume Data Results

STUDIES		MEAN	STANDARD DEVIATIONS	VARIANCES
Period 1	Before	40.48	8.08	63.34
	During	38.06	8.59	71.57
	After	40.15	7.71	57.76
Period 2	Before	48.06	10.16	100.23
	During	46.66	13.36	173.13
	After	46.75	12.43	150.06
Period 3	Before	64.21	10.86	114.40
	During	64.69	10.87	114.63
	After	67.51	12.13	142.73
Period 4	Before	79.06	11.89	137.26
	During	80.90	8.34	67.59
	After	77.69	9.19	82.02
Period 5	Before	33.51	7.47	54.24
	During	33.24	8.83	75.63
	After	33.93	7.47	54.23

TABLE 7. Significant Speed Factors

STUDIES	BEFORE/DURING	DURING/AFTER	BEFORE/AFTER	STUDENT'S t
Period 1	0.008	0.023	0.163	1.960
Period 2	0.042	0.300	0.013	1.960
Period 3	0.021	0.054	0.027	1.960
Period 4	0.000	0.005	0.004	1.960
Period 5	0.048	0.064	0.015	1.960

TABLE 8. Significant Volume Factors

STUDIES	BEFORE/DURING	DURING/AFTER	BEFORE/AFTER	STUDENT'S t
3 Lanes				
Period 1	0.046	0.047	0.002	1.670
Period 2	0.017	0.007	0.030	1.670
Period 3	0.011	0.040	0.025	1.670
Period 4	0.001	0.040	0.029	1.670
Period 5	0.017	0.004	0.016	1.670
2 Lanes				
Period 1	0.034	0.010	0.021	1.670
Period 2	0.010	0.012	0.006	1.670
Period 3	0.057	0.020	0.049	1.670
Period 4	0.060	0.053	0.017	1.670
Period 5	0.028	0.037	0.065	1.670
Combined				
Period 1	1.196	1.056	0.172	1.670
Period 2	0.486	0.029	0.476	1.670
Period 3	0.182	1.009	1.182	1.670
Period 4	0.739	1.508	0.531	1.670
Period 5	0.136	0.348	0.232	1.670

TABLE 9. Brake Light Applications by Minute Analysis

STUDIES		MEAN	STANDARD DEVIATIONS	VARIANCES
Period 1	Before	2.06	1.98	3.93
	During	1.78	1.72	2.98
	After	1.88	2.18	4.48
Period 2	Before	1.48	1.68	2.82
	During	1.79	1.61	2.58
	After	1.09	1.53	2.34
Period 3	Before	3.64	1.36	5.58
	During	3.82	3.48	12.10
	After	3.09	2.17	4.71
Period 4	Before	3.09	2.72	7.40
	During	5.73	3.43	11.77
	After	4.03	3.12	9.76
Period 5	Before	1.42	1.37	1.88
	During	3.27	4.42	19.52
	After	1.12	1.19	1.42

TABLE 10. Significant Factors for Brake Light Applications

STUDIES	BEFORE/DURING	DURING/AFTER	BEFORE/AFTER	STUDENT'S t
Period 1	0.612	0.210	0.357	1.670
Period 2	0.766	1.810*	0.986	1.670
Period 3	0.246	1.023	0.985	1.670
Period 4	3.464*	2.105*	1.304	1.670
Period 5	2.297*	2.699*	0.949	1.670

*Test was significant at 5 percent level.

are powered from 117 Volts AC. Because of the difficulty in testing the actual units at the study site, similar units and the electric schematics for each were obtained and testing was conducted at the Gulf Freeway Control Center.

The light source has two separate 6 Volt 36 Watt incandescent lamps powered from a 5.5 Volt DC transformer. Normal operations of the light source require that only one lamp be illuminated at any time. The electrical connections to the lamps are arranged such that should the first lamp's filament open and no longer provide illumination, the second lamp is automatically powered (Figure 12). In this manner, a back-up light source is provided. Testing the back-up circuit by disconnecting one side of the first lamp's filament indicated that the back-up circuit does work. The physical shape of the round lamp bulb is similar to that used in current automotive headlamps with the four-inch diameter lens being slightly fluted. In testing the light dispersion from the lamp, it was found that a 4-inch illuminated spot immediately in front of the lamp was 1) 36 inches in diameter at 35 feet from the lens and 2) 72 inches in diameter at 70 feet from the lens.

The overheight load detector is composed of two photoelectric cells mounted 8 inches apart for sensing the light change, a printed circuit board containing the electronic components and circuits, an electrically operated detection counter, an output relay, and the power supply. The basic logic of the circuit is to detect the changing light intensity across the two photoelectric cells in one direction only and engage the output relay. Each photoelectric cell (Photo-Darlington transistor) reacts as an variable resistor, increasing resistance with increasing light intensity and is sensitive to the infrared light region (7,300 Angstroms).

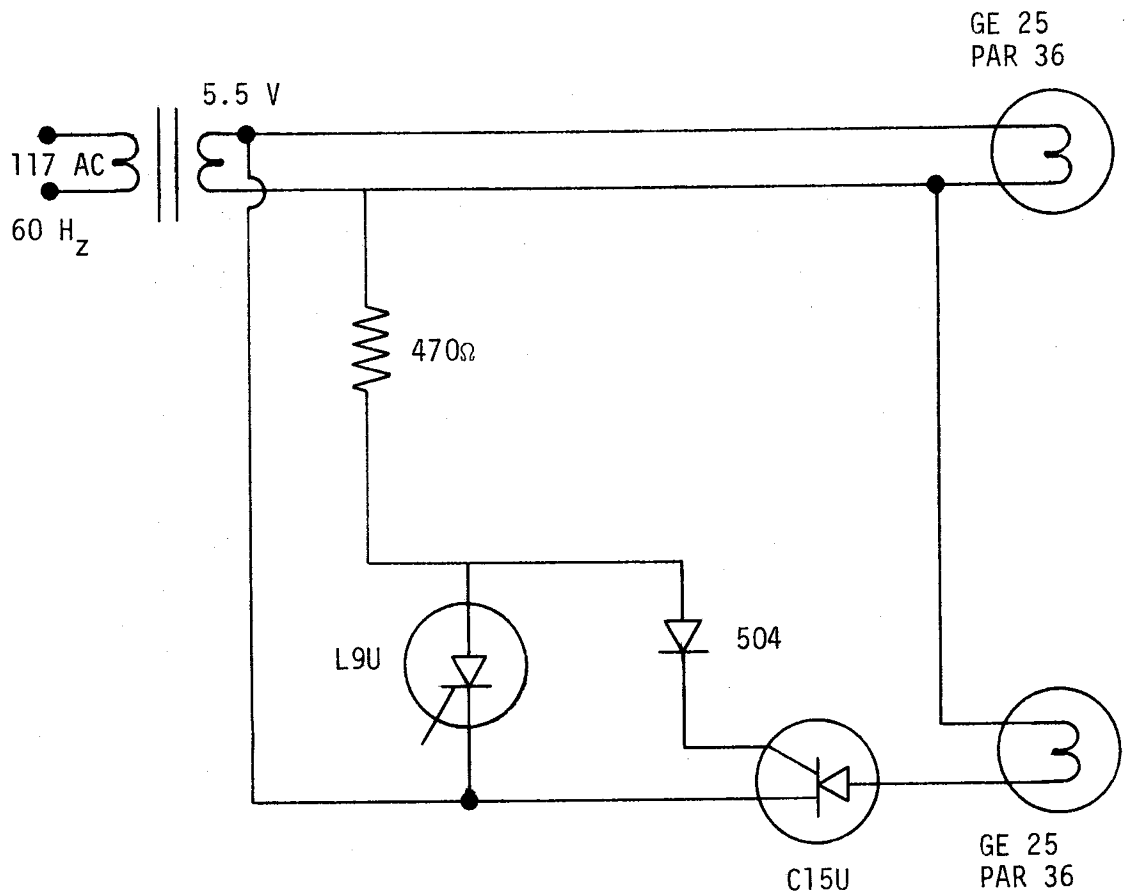

FIGURE 12. Light Source Circuit Diagram

The Photo-Darlington transistor is wired to a capacitance circuit which requires that the resistance change faster than a capacitance discharge. Tests conducted on the sensors reactions indicated that the image shadow must pass across the two cells at a speed greater than 2 miles per hour for detection to occur. Otherwise, the AC coupled circuit will adjust for the decreased light intensity on the sensors.

Each sensor puts out a 5 Volt DC pulse upon detection regardless of the image travel direction. The solid state components are connected so that the pulses from the sensors must arrive in the correct sequence. If correct, the output relay is engaged; if not, the circuit automatically resets. The output relay has an adjustment for changing the length of time the circuit can keep the relay engaged; from 3 to 30 seconds. Upon each relay actuation, the electrically operated counter is actuated.

In determining the response time of the circuit, manufacturer specification on individual components within the detector were reviewed as well as documenting actual timing patterns with the aid of an oscilloscope. Tests revealed that the circuit was not able to respond to the passage of an object if the travel time between the two sensors was less than one millisecond. The Photo-Darlington has typical delay times of 400 microseconds which account for approximately 60 percent of this time. One millisecond corresponds to an image speed of approximately 450 miles per hour. Complete test results are indicated in following paragraphs.

In determining what minimum size object would be detected by the overheight load detection system, two problems occurred. One problem is light diffraction or the scattering of light around an object and second is the apparent multiplication of the object speed due to the ratio of object and image distances from the light source. As indicated in Figure 13. A one-half-inch object will be detected only if it passes within 3 feet of the detector, an one-inch object would be detected at approximately 20 feet. The sensors cannot detect a sufficient light intensity reduction past these distances due to the diffraction of light around the objects regardless of the objects' speeds.

The second problem occurred when an object approached 1) the light source and 2) the minimum travel time between sensors. If an object is rotating about a center point (light source) at a constant angular speed ω, then the object's shadow would also be moving at the same angular speed but the linear speed would be dependent upon the distance from the center point. Let S_1 be the linear speed of the object at a distance r from the light source and S_2 the linear speed of the shadow at distance R. Then

$$\omega = \frac{S_1}{r} = \frac{S_2}{R}$$

Solving Equation 1 for the speed of the shadow, S_2 becomes

$$S_2 = S_1 \frac{R}{r}$$

If the object speed is assumed to be 50 MPH and the object is moved at various distances from the light source (r) and the light source-to-detector distance (R) is known, then the shadow speed can be taken from Table 11. For instance, if the object is 40 feet from the light source and the light source is 80 feet from the detector, the shadow of the object would pass across the detector at approximately 100 MPH. The closer a moving object is to the light source, the greater is the apparent speed of the object's shadow. Tests conducted on the detection system verified these facts. Objects within five feet of the light source had

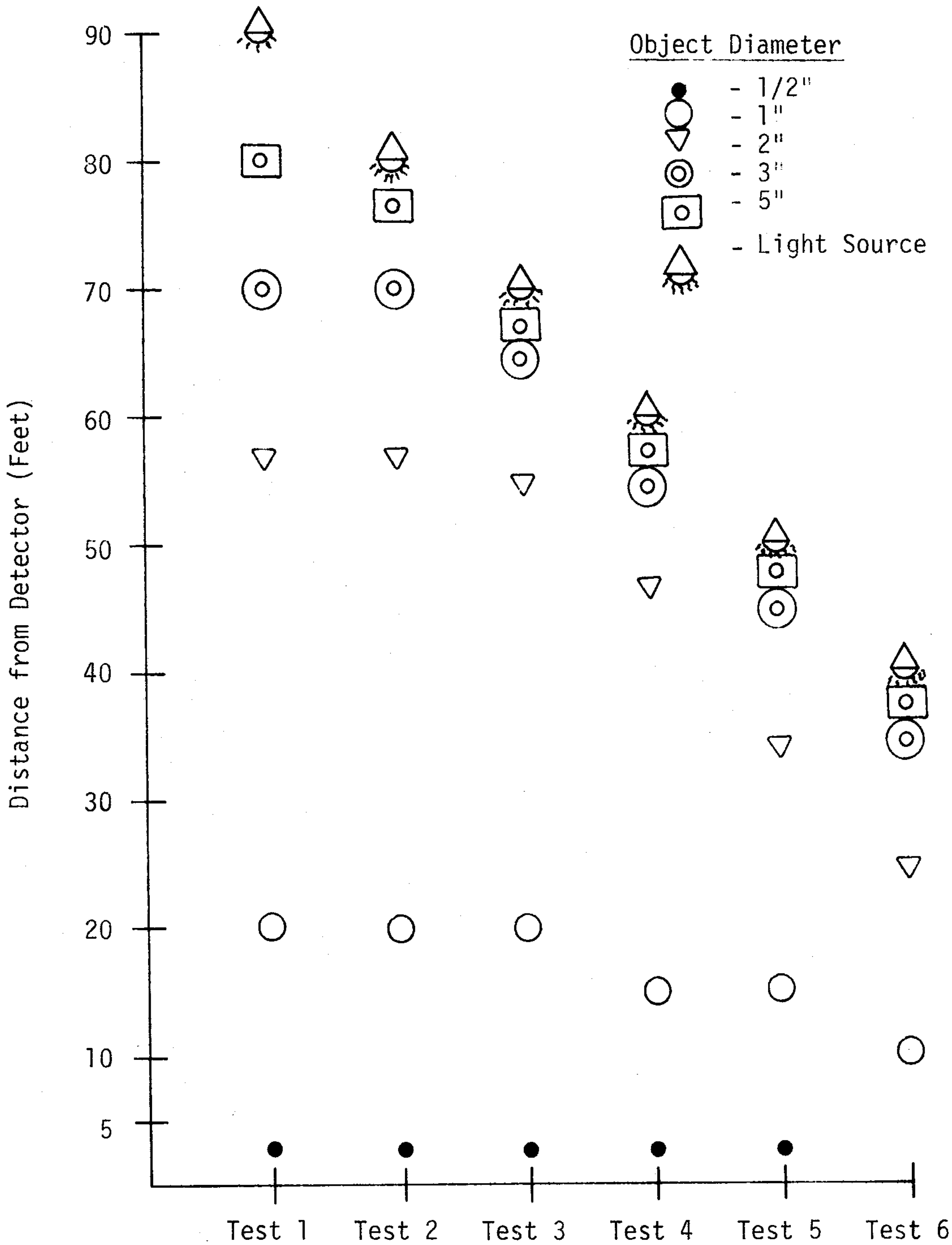

FIGURE 13 Maximum Distances for Object Detection with Different Light Source - Detector Distances

TABLE 11. Shadow Speeds (MPH) at Detector for Various Light-to-Detector and Light-to-Object Distances (Object Speed = 50 MPH)

Distance from Object to Light Source (feet)	Distance from Light Source to Detector (feet)				
	90	80	70	60	50
80	56	---	---	---	---
70	64	57	---	---	---
60	75	57	58	---	---
50	90	80	70	60	---
40	112	100	87	75	62
30	150	133	117	100	83
20	225	200	175	150	125
10	450	400	350	300	250
5	900	800	700	600	500

to be moved very slowly (in comparison to greater distances) in order for detection to occur.

Detector Test Summary

The light source and photoelectric detector are separated by approximately 80 feet at the study site. Based on the tests conducted (Figure 13, Test 2), an one-inch object may be detected if the object is in the lane adjacent to the detector. If the one-inch object is in any of the other three lanes, it will not be detected. An object two inches or greater may be detected out to approximately 55 feet from the detector. This would place the object in the furthermost lane from the detector. Also, the closest an object can approach the light source (without using the emergency parking lane) is approximately 15 feet. Therefore, excessive shadow speeds should not be encountered providing the overheight load is not exceeding the speed limit. Radio antennas will not be detected. Opaque objects were used to simulate diesel exhausts but were not detected.

Inspection of the detection system during moderate to heavy rain showers revealed the fact that run-off water from the pavement on the overhead connection ramp was falling on top of and directly in front of the detector. The water absorbed sufficient light energy to activate the sensors and consequently the warning system was operated. Modifications to the detector installation were not made to inhibit the water from activating the system before the completion of the study.

Effectiveness of Protection

During the control studies, only one overheight load was observed to use the I.H. 45 northbound roadway. The warning system was already operating when the vehicle entered the study section. The driver did divert via the I.H. 10 westbound exit. Also, the author observed one other overheight load, at a later time, that was detected. The driver did divert to the I.H. 10 westbound exit and the overheight load, a crane and boom on a trailer, struck the Hogan Street superstructure. No damage was sustained by the exposed girders. With the exception of these two cases, no evidence was obtained within the scope of the study that would determine the number of high loads detected and diverted. There is evidence that the detection and warning system is not totally successful in sensing and diverting all overheight loads.

District 12 of the SDHPT welded steel plates to the last three I-beams of the Hogan Street overpass (Figure 14) that function as skid plates. Shortly after the photograph was taken in Figure 14, the entire under-surface of the steel plated area was painted. Periodic inspections of the painted surface revealed scratches and skid marks. Also, the low clearance signs on the approach side of the structure have been damaged (Figure 15). Attempts were made to determine if the detection and warning system had been in operation when these high loads struck the structure.

Initially, a counter in the warning system's controller was designed to operate each time an overheight load was detected. However, observations of the counter indicated overcounting because of relay contact bounce. Changes to the circuits in the controller were made by District 12 forces. An additional counter was implemented which records the number of times the warning system is activated. The original counter is used to record the number of actuations by the detection system. Regular visits to the controller cabinet indicated that the two counters function but over-counting is still a problem. Therefore, the presence of a new skid mark or sign damage at the Hogan Street overpass and a check of the counter readings in the controller cabinet could not be used to verify the fact that the detection and warning system had been in operation.

An inspection of the skid marks on the painted surface revealed that the majority of the marks were long, narrow, and parallel to the direction of travel. Based on observation, an overheight load composed of some type of equipment that has a long boom made the marks. Booms may be missed due to the limitations of the detection system, as discussed, or to the bouncing effect caused by the undulating road surface.

Summary of Effectiveness

Even though conclusive results on the effectiveness of the warning system to divert overheight loads were not obtainable within the scope of this study, there is evidence that the detection and warning system does provide a measure of advance warning to the traffic approaching Hogan Street overpass. Further, it was indicated by this study that this advanced warning system was not detrimental to the operation of the freeway.

FIGURE 14. SKID PLATES UNDER HOGAN STREET OVERPASS ON I.H. 45 NORTH

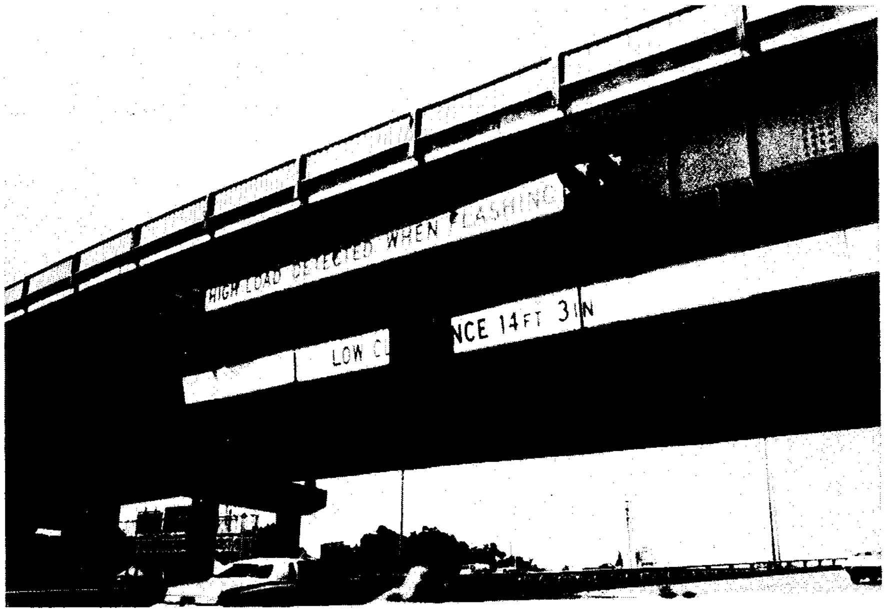

FIGURE 15. LOW CLEARANCE SIGN DAMAGE

REFERENCES

1. Table by State Department of Highways and Public Transportation, District 12, Motor VEhicle Registrations. Table shows the number of vehicle registrations for the State of Texas by County for April 1973 through May 1974.

2. Houston FACTS, published by Houston Chamber of Commerce, Research Division, January 1, 1975, P. O. Box 53600, Houston, Texas 77052.