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16. ABSTRACT

With a steadily increasing amount of roadway reconstruction, the need for a method to determine the minimum degree of reconstruction required to restore an existing roadbed to a state in which it may serve present day traffic volumes and render maintenance-free service for an extended period has become increasingly important.

The problem encountered in designing the reconstruction of an existing facility or the second stage of a two-stage project is, of course, entirely different from that which occurs with all new construction. In the latter case, samples of embankment soils are tested by the R-value design procedure under moisture and density conditions which are estimated to be the worst that will occur during the lifetime of the pavement. From the results of these tests, the design R-value is selected and a necessary thickness of base or subbase chosen to provide the required cover in accordance with the design formula.

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PAVEMENT OVERLAY DESIGN BY DEFLECTION MEASUREMENTS

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Prepared for
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Highway Conference
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PAVEMENT OVERLAY DESIGN

BY DEFLECTION MEASUREMENTS

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For Presentation at
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and Highway Conference
at Reno
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INTRODUCTION

With a steadily increasing amount of roadway reconstruction, the need for a method to determine the minimum degree of reconstruction required to restore an existing roadbed to a state in which it may serve present day traffic volumes and render maintenance-free service for an extended period has become increasingly important.

The problem encountered in designing the reconstruction of an existing facility or the second stage of a two-stage project is, of course, entirely different from that which occurs with all new construction. In the latter case, samples of embankment soils are tested by the R-value design procedure under moisture and density conditions which are estimated to be the worst that will occur during the lifetime of the pavement. From the results of these tests, the design R-value is selected and a necessary thickness of base or subbase chosen to provide the required cover in accordance with the design formula.

Designing the reconstruction or determining the required thickness of a second stage for an existing roadway presents another problem since the most economical reconstruction requires that full benefit be derived from the materials existing in the structural section. In this case, the normal R-value criteria is not quite valid since the conditions of moisture and density assumed during preliminary design may not have occurred. Also, it is a well-known fact that many years of successively heavier traffic loadings gradually tend to increase in-place soil strength. Another factor which is difficult to evaluate is the residual strength of an AC surfacing or cement treated base. Here, the hardening or curing induced by age may lend considerable slab strength to the system even though there is continuous visible distress. The prime importance of pavement deflection data is that it gives the highway engineer an indication of the total in-place structural strength of an existing roadway and, thus, provides an extremely valuable tool for determining the degree of additional construction required.

The California Division of Highways has long recognized the importance of pavement deflections, having made measurements as early as 1938 with permanently installed gage units. This was expensive and only a few readings could be taken per day. In 1955, as a result of a statewide deflection study[1] it was possible to assign critical levels of transient deflection for several structural sections. These criteria, which are shown in Table I, have been utilized by the Division of Highways since 1955 in planning the reconstruction of existing highways.

Table I

Maximum Tolerable Deflection Levels

Thickness of Pavement	Type of Pavement	Max. Permissible Deflection for Design Purposes
8-in.	Portland Cement Concrete	0.012-in.
6-in.	Cement Treated Base (Surfaced with Bituminous Pavement)	0.012-in.
4-in.	Asphalt Concrete	0.017-in.
3-in.	Plant Mix on Gravel Base	0.020-in.
2-in.	Plant Mix on Gravel Base	0.025-in.
1-in.	Road Mix on Gravel Base	0.036-in.
1/2-in.	Surface Treatment	0.050-in.

These permissible deflections were established using data obtained on heavy trafficked roads (9 T.I.) and since have been adjusted for a range in traffic index (T.I.) from 6 to 10 using information obtained in a study of AC surfacing fatigue. Figure 1 shows tolerable deflection levels for various types of pavement and ranges of traffic index.

From 1955 through 1967, approximately 135 projects representing 450 different roadways have been the subject of deflection studies for the purpose of recommending appropriate reconstruction. Original studies were done with the Benkelman beam, Figure 2, followed later by the traveling deflectometer, Figure 3, and most recently by the Lane-Wells Dynaflect which will be explained later in more detail. Measurements taken before and after corrective treatment have provided valuable data on the deflection damping properties of various roadway materials.

The sum total of our deflection attenuation experience to date is shown by Figure 4 in which average percent reduction in deflection is plotted against increase in inches of gravel equivalence for 48 completed projects. This plot is the basic tool for planning reconstruction of roadways based upon deflection measurements.

TEST PROCEDURE

Prior to making deflection measurements, the project file is studied for information on variations in structural section, traffic volume, foundation and drainage conditions, and unusual occurrences during construction which may have had an effect upon the performance of the roadway. From this data and visual examination of the project, test sections considered to be representative are selected. Approximately 1000 feet per mile is tested on each project. Deflection test data is separated into the categories of fill, cut, cracked, uncracked, travel lane and passing lane. Examination of average deflections for each of these categories can frequently indicate the nature or cause of early pavement distress and the practicability of utilizing more than one type of corrective treatment.

As an example, a deflection investigation of U.S. 101 near Santa Barbara about 1963 produced sufficiently diverging deflection levels in cuts and fills to warrant separate recommendations. The reconstruction involved the placement of an AC blanket in cut sections with substantial dig-out reconstruction required in the fills. This selective reconstruction was found to be economically feasible since fills and cuts on this particular roadway were relatively long.

In addition to the mean deflection, the evaluated deflection level (80 percentile) for each test section is determined. (The evaluated deflection level is the point at which 20% of the readings are higher and 80% are lower.) Usually a large discrepancy between the evaluated and mean deflection levels indicates a disproportionate influence of a few high readings so that the mean value may be more realistic as the basis for the design of reconstruction.

In order to illustrate the method of analysis and procedure for recommendation of corrective treatment based upon deflection data, we shall examine what might be considered a typical case history of a particular roadway. The information presented below (Table 2) was actually acquired during a recent deflection investigation of the streets of a medium size city in the Central Valley of California.

Table 2

Test Section	Deflection (Inches) Mean OWT	Deflection (Inches) Mean IWT	Deflection (Inches) Evaluated (80% Level)	Appearance
1)	0.055	0.028	0.106 (35)**	Intermittent "alligator" cracking and shrinkage cracking.
2)	0.043	0.031	0.064 (28)**	Continuous to intermittent "alligator" cracking in both wheel tracks of all lanes.

**Number of individual deflection measurements.

The subject roadway had a structural section consisting of 2" of AC surfacing over 4" of aggregate base over 4" of aggregate subbase. The design traffic index was assumed to be 6.5.

The evaluated deflection levels for the two test sections were 0.106" and 0.064". For Test Section No. 1, however, we note a mean outer wheel track deflection level of 0.055". The wide discrepancy between the mean (0.055") and the evaluated (80 percentile) (0.106") levels indicates that the evaluated deflection level was greatly influenced by a few isolated high readings and, thus, is not representative of the test section as a whole. With this in mind, the evaluated deflection level of Test Section No. 2 (0.064") is selected as the design deflection level. Based upon a T.I. of 6.5 and the utilization of a 3" AC surfacing, it is determined from Figure 1 that a deflection level of 0.030" can be tolerated. It is, therefore, necessary to effect a reduction in the deflection level of 0.064" minus 0.030", or 0.034". This requires a $\frac{0.034"}{0.064"} = 53\%$ reduction in deflection. From Figure 4 we note that an increase of 10.5" in gravel equivalence is required to reduce the deflection level by 53%. For a 3" AC surfacing the gravel equivalence is 3.0 x 1.9" = 5.7". It will, therefore, be necessary to provide 10.5" minus 5.7" = 4.8" of additional gravel. A possible reconstruction would, therefore, be the placement of a 3" AC surfacing over 5.0" of aggregate base directly over the existing roadway. This type of repair is practical, where vertical controls are non-existent, otherwise, a digout type repair providing the same net increase in gravel equivalence is necessary.

Another practical approach to the same problem which would cost less takes into consideration the type of distress on the roadway. Here we note intermittent to continuous "alligator" cracking in both wheel tracks. Because "alligator" cracks are usually small (2" to 5" in diameter) we can reasonably assume that the existing pavement will act independently of the new surfacing in much the same manner as an aggregate base. Therefore, consideration should be given to the possibility of the placement of a thin AC blanket which would permit a higher tolerable deflection level. This approach could be considered as permitting a high deflection condition to exist rather than eliminating it by a major reconstruction. For a 2" AC surfacing, Figure 1 indicates a tolerable deflection of 0.040". It would, therefore, be necessary to reduce the design deflection level of 0.064" to 0.040" which requires a 38% reduction in deflection. From Figure 4, a 2" AC blanket (3.8" gravel equivalence) provides a 37% reduction in deflection. This is considered close enough to recommend a 2" AC surfacing for the repair of this facility.

In either case, isolated areas of high transient deflection or advanced distress should be subject to substantial digout type repair prior to the application of the corrective treatments described above.

Where it is possible to utilize the existing structural section in its entirety, placement of reconstruction directly over existing surfacing permits comparable results with thinner reconstruction. This is demonstrated by the results of the deflection study on road 06-Kin,Tul-43, which at the time of the investigation had a structural section consisting of 3" AC, 6" of low strength (Class "C")* CTB, 5" of aggregate base, and 11" of imported borrow. The results of deflection measurements prior to reconstruction are presented by Table 3.

Table 3

Deflection Data From Project 06-Kin,Tul-43

Northbound Lanes

	Uncracked		Cracked	
	OWT	IWT	OWT	IWT
Mean Deflection	0.036"	0.028"	0.057"	0.047"
Evaluated Deflection	0.049"	0.030"	0.084"	0.066"

Southbound Lanes

	Uncracked		Cracked	
	OWT	IWT	OWT	IWT
Mean Deflection	0.034"	0.032"	0.049"	0.031"
Evaluated Deflection	0.042"	0.038"	0.068"	0.038"

Summary

	Uncracked	Cracked
Mean Deflection	0.032"	0.047"
Evaluated Deflection	0.042"	0.068"

Based upon an average deflection level for the cracked areas of 0.047", the design criteria in use at that time indicated a need for increase in gravel equivalence of 15". It was recommended that this be accomplished by scarifying the existing surfacing and base to a depth of 8" to be followed with an addition of sufficient cement to form a CTB with a minimum compressive strength of 500 psi in seven days.

*1% to 2-1/2% cement

It was further recommended that the entire roadway was to be blanketed with a 3" AC surfacing. Because of the absence of vertical controls, the District elected to place a 6" layer of cement treated base and a 3" AC blanket directly over the original roadway, which provided for an increase in gravel equivalence of 16". A graphic presentation of deflection data before and after reconstruction from one test section is shown by Figure 5. Follow-up deflection measurements indicated a reduction in transient deflection level by an average of 71%. This project was considered quite successful since the deflection levels after application of corrective treatment were reduced below the critical level.

Detailed descriptions of the results of several other interesting deflection studies completed by the Materials and Research Department are included in a paper[2] presented at the 45th Annual Highway Research Board meeting in January 1966.

CURRENT RESEARCH

The primary objective of the department's current deflection research program involves the modification of our current limiting deflection criteria so that it will be possible to make appropriate adjustments based on traffic volumes.

Another study involves evaluation of the shape or curvature of the deflected basin or the area of influence of the test load which many investigators feel is a reliable indicator of pavement performance. Of interest in this phase of work is the evaluation of the "curvature meter", Figure 6, with which direct measurements of pavement radii of curvature under load are possible.

We also, as a matter of course, make follow-up measurements on projects reconstructed subsequent to deflection investigations. These before and after deflection measurements provide very useful attenuation data for different roadway materials.

The Materials and Research Department is presently evaluating a new system for measurement of pavement deflection which was developed by the Lane-Wells Highway Products Company of Houston, Texas. This device, known as the "Dynaflect" (Figure 7) is a small, self-contained trailer-mounted unit which can be towed behind a passenger vehicle and operated by the driver from inside the tow vehicle.

The "Dynaflect" System is composed of a dynamic force generator which consists of a pair of unbalanced flywheels which revolve counter to one another at eight cycles per second, a set of five motion sensing devices (geophones) and a motion measuring instrument. To make the unit operational a tow vehicle with a 12 volt electrical system is utilized. By means of a hydraulic system, the trailer is lifted off the pavement surface and a pair of rigid test wheels are brought down into contact with the pavement to support the trailer unit. Utilizing the static weight of the trailer which is 1,600 pounds and the dynamic force generator, a 1,000 pound peak to peak eight cycles per second oscillatory load is produced onto the pavement surface. The resultant amplitude of motion is sensed by a set of five geophones which are also brought into contact with the pavement. They are located along the tongue of the trailer at one foot intervals out from the center of loading. With this device, it is not only possible to measure the maximum deflection under the loading, but also the shape of the deflected basin which is produced.

The Materials and Research Department of the California Division of Highways has established a good correlation between the Dynaflect and our standard deflection measuring devices (Benkelman beam and traveling deflectometer). It is, therefore, possible to use the Dynaflect on an operational basis for recommending pavement overlays utilizing a pre-established correlation. Figure 8 shows a correlation between deflection measurements obtained by the Dynaflect and those produced by the traveling deflectometer under a 15,000 pound single axle load. For deflection analysis purposes, it is sufficient to read only the single geophone at the center of loading, rather than the complete set of five geophones.

During the last year, 15 projects representing some 90 different roadways have been subject to deflection study for purposes of recommending reconstruction utilizing the Dynaflect. The same test procedure is followed with the Dynaflect as with the Benkelman beam and traveling deflectometer with exception of a conversion to standard deflection level. It is just a matter of converting the evaluated 80 percentile Dynaflect deflection level for a particular test section to an equivalent Benkelman beam deflection utilizing Figure 8. The Benkelman beam deflection level is then used for design purposes with our present method using Figures 1 and 4 as usual. A report[3] titled "Comparison of Deflectometer and Dynaflect for Asphalt Concrete Overlay Design" was presented to the California Transportation and Public Works Conference in January 1968.

Because the Dynaflect is trailer-mounted and may be towed by a passenger vehicle, it has a far greater degree of mobility than the Benkelman beam test truck or traveling deflectometer. It is, therefore, better for work in mountainous terrain and on projects of a limited nature.

Due to the relatively light loading produced by the Dynaflect, it is possible to obtain deflection measurements on unsurfaced road beds during various stages of construction. This has generally not been possible with the deflectometer or the Benkelman beam due to distortion and up-thrust between the loaded dual wheels. This device presents the possibility of locating weak spots on going construction projects for corrective treatment prior to completion of the structural section.

Our evaluation of the Dynaflect is being conducted in co-operation with the U.S. Bureau of Public Roads and a final report of our findings will soon be published. A similar study of the results of correlation measurements with the Benkelman beam and Dynaflect on several Texas State highways was reported[4] to the 45th Annual Meeting of the Highway Research Board in 1966.

CONCLUSIONS

It is obvious that the most economical reconstruction of any facility requires that full benefit be derived from the existing structure. With respect to highway construction in California, this factor becomes increasingly important with time since an ever growing proportion of our highway construction involves the reconstruction of the existing alignment. Pavement deflection measurements provide an excellent indication of the residual strength of an in-place structural section which very frequently belies visual appearance. Thus, a representative testing program and a realistic examination of the existing data can, in many instances, indicate areas where significant savings are possible. Therefore, I suggest that prior to corrective treatment of any major highway for the primary purpose of strengthening the structural section, a deflection study be initiated and that the resulting data be considered in the design of the reconstruction.

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VARIATION IN TOLERABLE DEFLECTION BASED ON A.C. FATIGUE TESTS

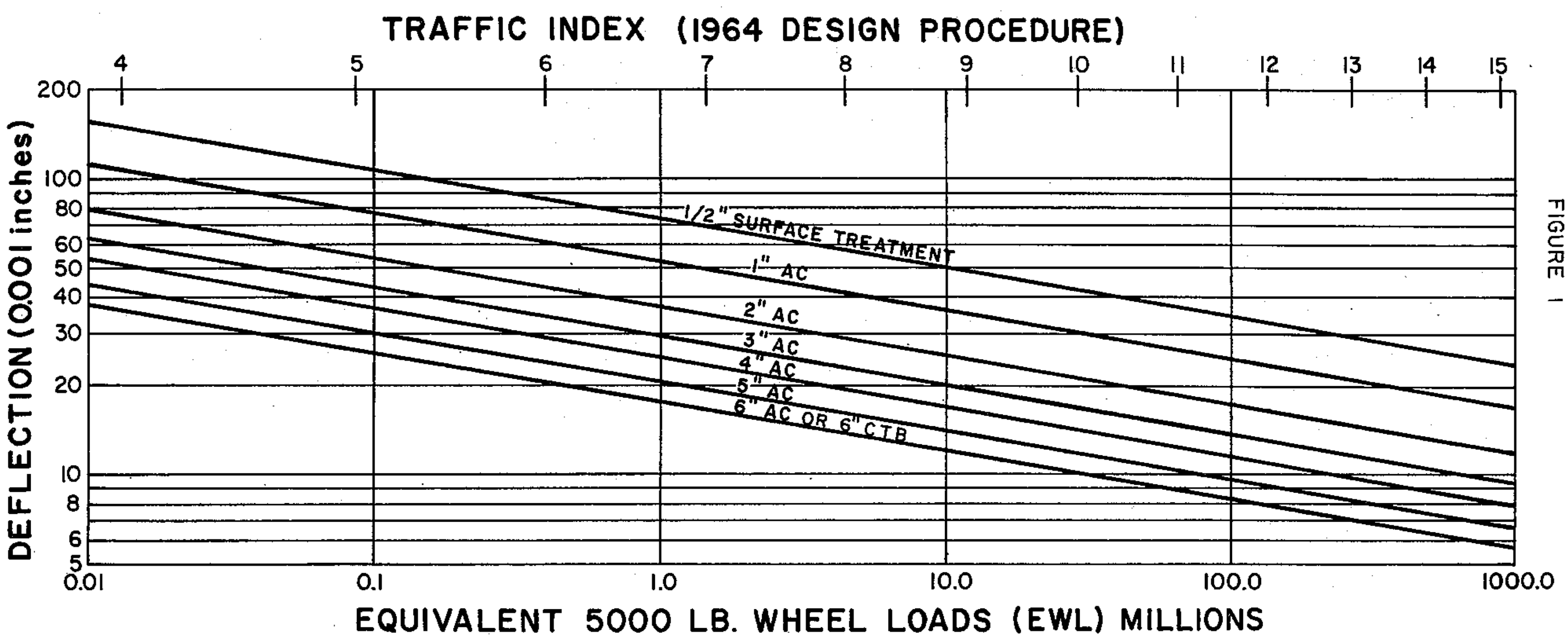
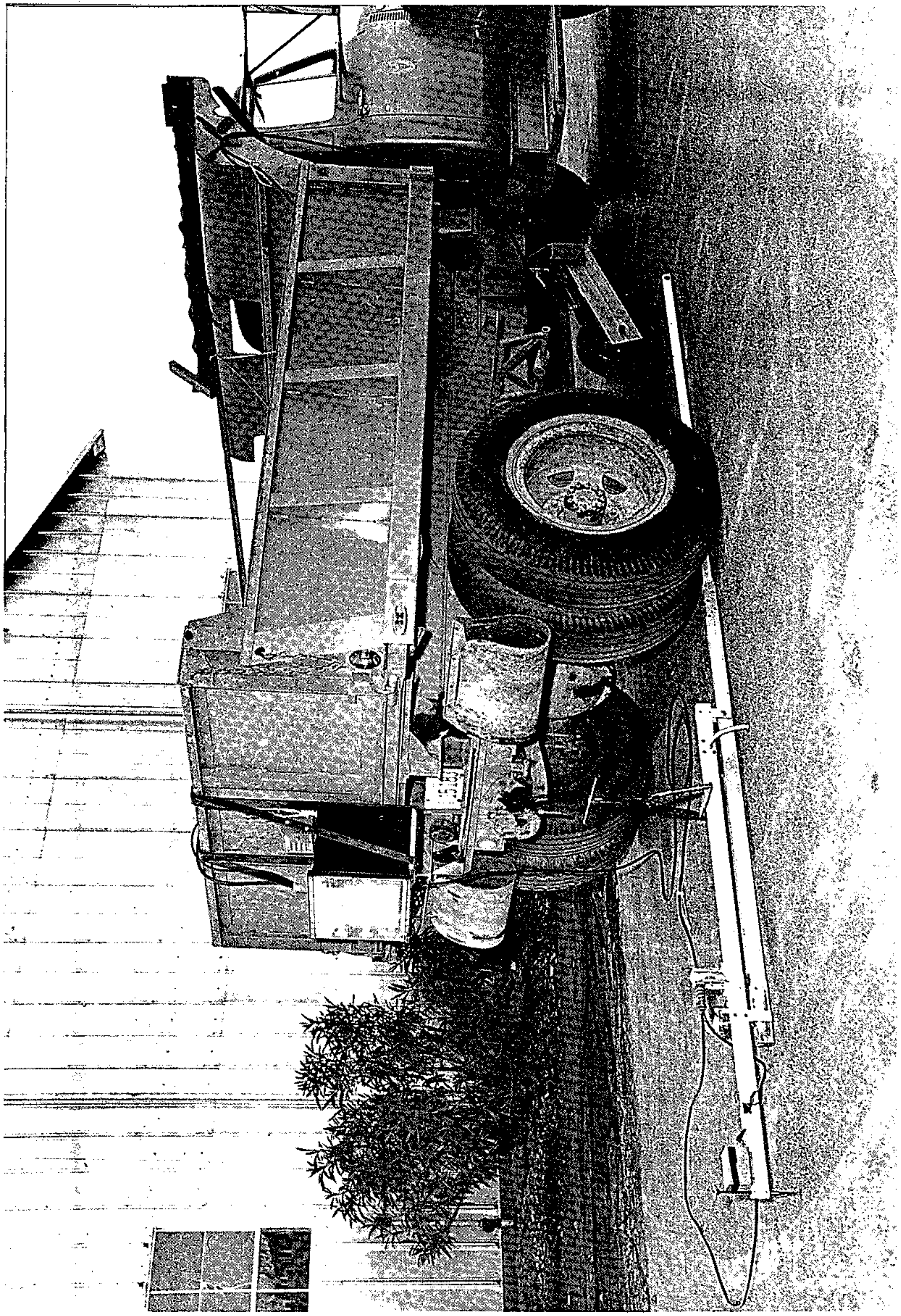


FIGURE 1

Figure 2



BENKELMAN BEAM WITH TEST TRUCK