

DYNAMIC EVALUATION AND TESTING OF TIMBER HIGHWAY BRIDGES

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SUMMARY

The dynamic response of glued laminated timber (glulam) girder bridges, longitudinal glulam deck bridges (longitudinal) and stress laminated (stress-lam) deck bridges has been determined from field test results using a heavily loaded truck. Deflections were measured for various vehicle speeds and transverse positions at the bridge midspan and were recorded using a high speed data acquisition system. A dynamic amplification factor (DAF) was computed from these data. The tests were part of a field testing program as part of a larger research study that includes analytical research as well. The experimental data described in this paper is only part of the data measured during the field testing which will be used to validate analytical models. The overall objective of the larger study is to determine the dynamic behavior of wood bridges so that reliable design specifications can be developed.

Key Words: timber, bridge, dynamic, glued laminated, girder, stress-laminated, deck, longitudinal.

1 INTRODUCTION

Wood has been used as a bridge material in the United States for hundreds of years. Despite the exclusive use of wood bridges during much of the 19th century, the 20th century brought a significant decline in the percentage of wood bridges relative to those of other materials. At the present time, approximately 8% of the bridges listed in the National Bridge Inventory are wood [1]. Recently, there has been a renewed interest in wood as a bridge material and several national programs have been implemented to further develop wood bridge systems. As a result of the Timber Bridge Initiative and the Intermodal Surface Transportation Efficiency Act, passed by Congress in 1988 and 1991, respectively, funding has been made available for timber bridge research [2]. A portion of this research is aimed at refining and developing design criteria for wood bridge systems. This project to investigate the dynamic characteristics of wood bridges is part of that program and involves a cooperative research Study between Iowa State University, the USDA Forest Service, Forest Products Laboratory, and the Federal Highway Administration. The first phase of the project addressed the dynamic performance of stress-laminated timber bridge decks [3]. The second phase of the project assessed the dynamic characteristics of glulam timber girder bridges [4]. The third phase of the project assessed the dynamic characteristics of longitudinal glued laminated timber deck bridges.

2 GENERAL RESEARCH PROGRAM

Field tests for this program was designed to observe bridge deflections and vertical accelerations and test vehicle vertical accelerations under both static and dynamic loading. Vertical deflections were measured for several vehicle velocities for two different bridge entrance conditions; the in situ condition and that due to an artificial bump at the entrance (which was used to simulate a potential rough bridge entrance condition that might occur in the field). The dynamic deflection data were compared to static deflections to quantify a dynamic amplification factor (DAF) for each test.

3 DESCRIPTION OF BRIDGES

Glulam timber girder bridges typically consist of a series of longitudinal glulam beams which support transverse glulam deck panels (Fig. 1). The girders are available in standard nominal widths ranging from 4 to 16 in. with girder depth limited only by transportation and pressure treating restrictions. Deck panels are usually 5 to 6 3/4 in. thick, 4 ft wide, and are continuous across the bridge width. Lateral support and alignment of the girders is provided by transverse bracing at the bearings and at intermediate locations along the span. Glulam girder bridges are feasible for spans ranging from 20 to 140 ft, although most are in the span range of 25 to 80 ft.

Stress-laminated timber bridge decks (see Fig. 2) consist of a series of wood laminations that are placed edgewise between supports and stressed together with high strength steel bars [5]. The bar force, which typically ranges

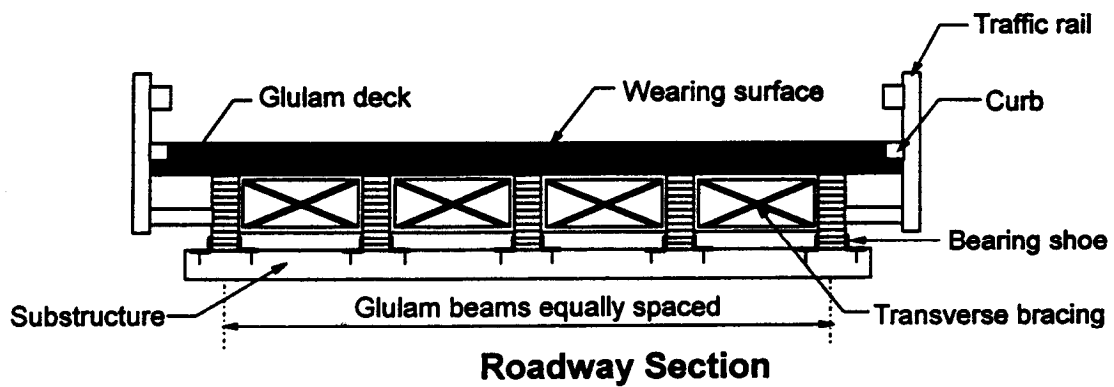
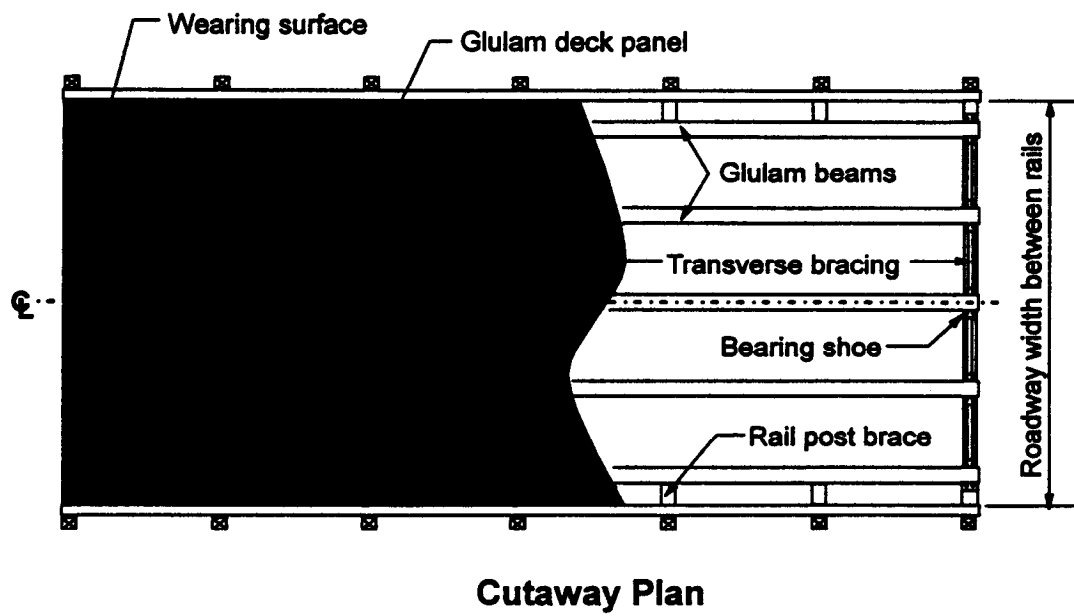


Figure 1 - Layout of a typical glulam girder bridge.

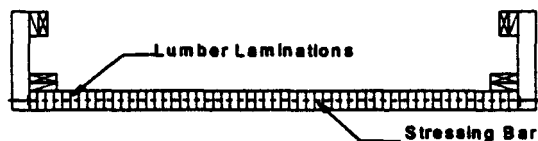


Figure 2 - Layout of typical stress-lam timber deck bridge

from 25,000 to 80,000 pounds, squeezes the laminations together so that the stressed deck acts as a solid wood plate. The concept of stress laminating was originally developed in Ontario, Canada, in 1976 as a means of rehabilitating existing nail-laminated lumber decks that delaminated as a result of cyclic loading and wood moisture content variations [6], [7]. In the 1980s, the concept was adapted for the construction of new bridges and numerous structures were successfully built or rehabilitated in Ontario using the stress-laminating concept. The first stress-laminated bridges in the United States were built in the late 1980s. Since that time, several hundred stress-laminated timber bridges have been constructed, primarily on low volume roads.

The superstructure of longitudinal panel deck bridges is constructed of glulam panels placed longitudinally between supports with the wide dimension of the laminations oriented vertically (see Fig. 3). All applied

loads and deflections are resisted by the deck without additional supporting members. There are, however, at least several transverse distribution beams attached to the underside of the deck to distribute the load to adjacent deck panels. They are connected with various types of connectors, the most common being through bolts and aluminum brackets. The glulam panels that make up the deck of this type of bridge range from 6 3/4 in. to 14 1/4 in. deep and 42 in. to 54 in. wide. Longitudinal panel deck bridges are economical and practical for clear spans up to approximately 40 ft. Multiple spans can be used to achieve longer crossings. When vertical clearance below the bridge is limited, the low profile of these bridges makes them desirable.

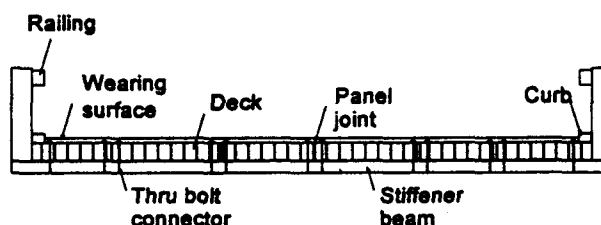


Figure 3 - Layout of typical longitudinal timber deck bridge.

Table 1 summarizes information about the sixteen bridges presented in this paper.

Bridge	Type	Span C-C Bearings (ft.)	width (ft.)	Bridge and Bridge Approach Pavement Type
Trout	Stress-lam deck	45.9	25.7	Asphalt
Little Salmon	Stress-lam deck	25.0	15.5	Unpaved
Lampeter	Stress-lam deck	22.2	29.6	Asphalt
Capitola	Stress-lam deck	23.4	35.6	Asphalt
Olean	Stress-lam deck	25.2	30.7	Asphalt
Schuykill	Stress-lam deck	34.9	26.0	Chip Seal
Wadesboro	Stress-lam deck	22.7	36.7	Asphalt
Teal	Stress-lam deck	31.5	23.8	Asphalt
Chambers County	Glulam girder	53.1	27.0	Asphalt
Mud Creek	Glulam girder	41.8	22.3	Chip Seal
Wittson - Span 1	Glulam girder	51.5	15.2	Asphalt
Wittson - Span 3	Glulam girder	102.0	15.2	Asphalt
Bolivar	Longitudinal deck	28.7	25.8	Asphalt
Scio	Longitudinal deck	21.3	31.2	Asphalt
Angelica 2	Longitudinal deck	20.3	28.9	Asphalt
Angelica 1	Longitudinal deck	31.2	35.7	Asphalt

Table 1 - Bridge description

4 INSTRUMENTATION

The dynamic response of each bridge was recorded during the passage of the three axle trucks traveling at constant velocity. Deflections were measured at midspan and the quarter span of each bridge span using Celesco potentiometer transducers (DCPT). Accelerometers were also mounted at several locations on the bridge at midspan and quarterspan. Details of the complete instrumentation can be found in [3].

Acceleration data were also collected on the vehicle simultaneously with the bridge DCPT data. The accelerometers were mounted on the vehicle frame over the rear axles and on the rear tandem axle.

5 TEST PROCEDURE

The dynamic load behavior of the bridge was evaluated for several vehicle velocities for in situ and artificially rough approach conditions at the bridge entrance. For the two lane bridges two different transverse vehicle positions were used: 1) eccentric, with the left wheel line (driver side) 2 ft to the right of centerline and, 2) concentric, with the axle of the truck centered on the bridge (i.e., straddling the centerline). For each bridge the test vehicles used were tandem axle dump trucks with steel leaf rear suspensions. The range of gross vehicle weights was 244.6 to 337.6 kN (55 to 75.9 kips).

In order to obtain a basis by which the dynamic load effects could be compared, crawl tests were performed for each loading position. During these crawl tests the vehicle velocity was approximately 5 mph. Deflections at higher velocities were then obtained with velocities ranging from 10 mph to safe upper limit speeds based on bridge alignments.

6 DATA PROCESSING

A plot of bridge deflection vs. vehicle position along the bridge length (using the vehicle front axle as a reference) was made for each DCPT location at midspan. A typical example of the dynamic vs. crawl deflections is given in Fig. 4. The maximum deflection obtained for crawl speed is referred to as δ_{stat} . The maximum dynamic deflection is referred to by δ_{dyn} .

A dynamic amplification factor (DAF) was computed for each bridge. Each DCPT location was scanned to find the maximum absolute crawl deflection and this data point was then used as the reference point for calculation of the DAF. As per recommendations by Bahkt and Pinjarkar 1989 [8], this approach yields the most useful design information. It should be noted that the data point with the highest crawl deflection typically had the highest dynamic response. The DAF was computed as:

$$DAF = 1 + \left(\frac{\delta_{dyn} - \delta_{stat}}{\delta_{stat}} \right) \quad (1)$$

where,

DAF = dynamic amplification factor
 δ_{dyn} = maximum deflection under the vehicle traveling at designated speed
 δ_{stat} = maximum deflection under the vehicle traveling at crawl speed

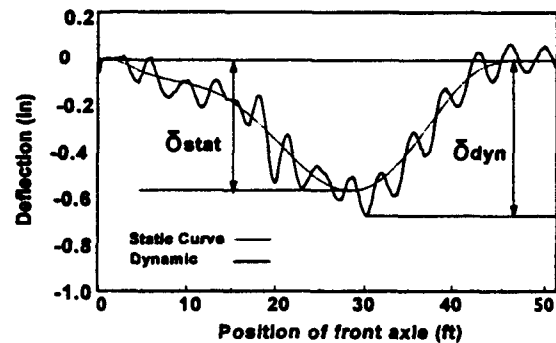


Figure 4 - Typical bridge dynamic deflection data for bridge tests.

Plots of the dynamic amplification factor are shown in Fig. 5. In this paper, only the DAF data associated with the in situ conditions are presented (i.e., no artificial rough entrance conditions are given). A summary of the maximum DAF and the experimental fundamental frequency for each bridge is shown in Table 2.

7 DISCUSSION OF RESULTS

From observation of the DAF data presented here and from more detailed analysis not presented in this paper, it is clear that DAF data from a finite number of experimental tests provides only limited information about the complex dynamic behavior of the vehicle/bridge system, [3] and [4] for more detailed discussion of this behavior. The DAF data do provide some limited information about the possible amplification of deflections that can be expected. The highest DAF recorded was 1.60 for Little Salmon bridge. However, it should be noted that the approach conditions for this bridge, which was an unpaved gravel road, were extreme and much worse than for the others, and definitely contributed to the high value. Angelica 2 bridge also had a very high DAF of 1.51 for the same reason. Mud Creek bridge had the next highest DAF of 1.38, but it also had a rough in situ bridge entrance condition.

Bridge	Maximum DAF	Experimental Fundamental Frequencies (Hz.)
Trout	1.23 ¹	3.9
Little Salmon	1.60 ²	8.6
Lampeter	1.10	10.6
Capitola	1.04	9.0
Olean	1.18	10.7
Schuykill	1.08	5.9
Wadesboro	1.10	9.6
Teal	1.18	7.4
Chambers County	1.12	6.4
Mud creek	1.38 ¹	8.9
Wittson - Span 1	1.15	5.9
Wittson - Span 3	1.09	2.8
Bolivar	1.32 ¹	7.4
Scio	1.07	9.8
Angelica 2	1.51 ¹	10.6
Angelica 1	1.10	8.8

¹ in situ conditions included rough entrance

² in situ condition included both rough and rough entrance

Table 2 - Summary of the experimental field data

The next highest DAF's were 1.32 for Bolivar bridge and was 1.23 for Trout bridge, which also had a rough in situ bridge entrance condition. In general, the DAF is magnified when the vehicle initial conditions (i.e., bounce and pitch motion) are magnified from either the approach conditions of the roadway or the entrance conditions at the bridge. For bridges with smooth entrance conditions, the highest DAF for the stress-lam bridges was 1.18 for both Olean and Teal bridges. For the glulam stringer bridges, the highest DAF for smooth entrance conditions was 1.15 for Span 1 of the Wittson bridge. Another trend worth noting is that the maximum DAF typically occurred for the vehicle eccentric load position (note that the Wittson spans and Little Salmon span were single lane).

In summary, while DAF data are not exclusive indicators of dynamic behavior, the experimental values represent actual field performance under the test conditions. As this study progresses and more data are available, further analysis and recommendations will be forthcoming.

8 ACKNOWLEDGMENT

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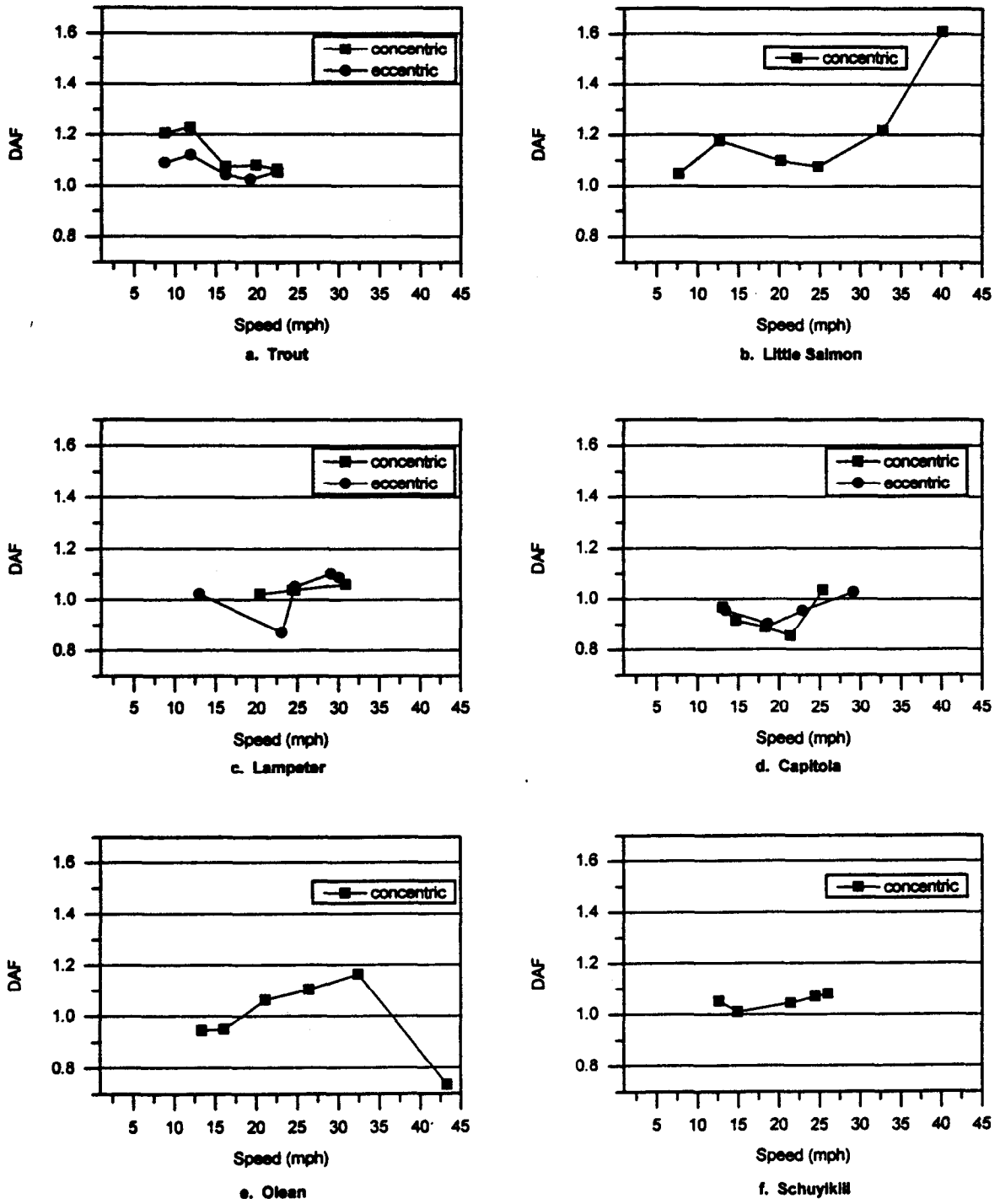


Figure 5 - Plots of in situ DAF.

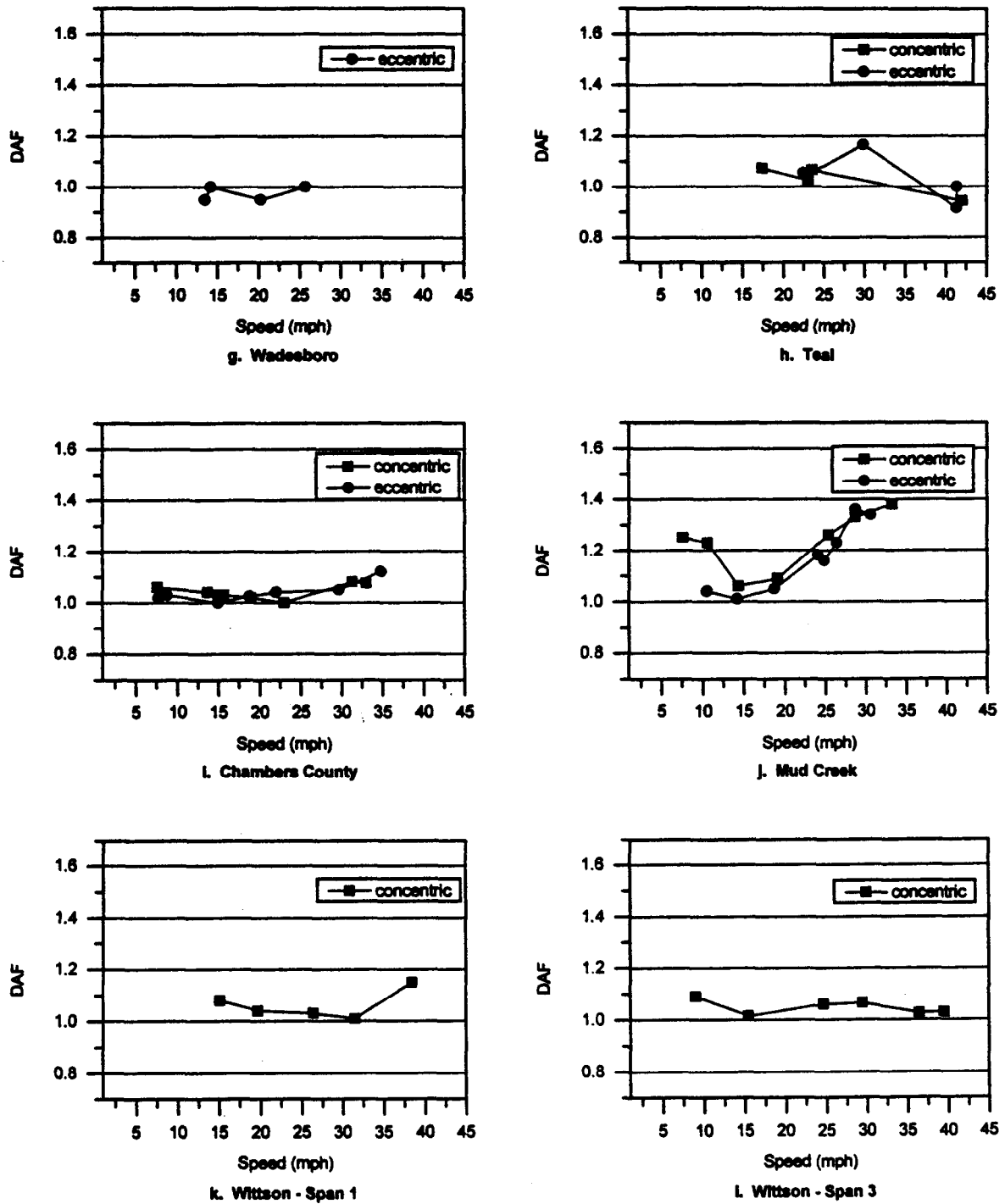


Figure 5 - Plots of in situ DAF (continued).

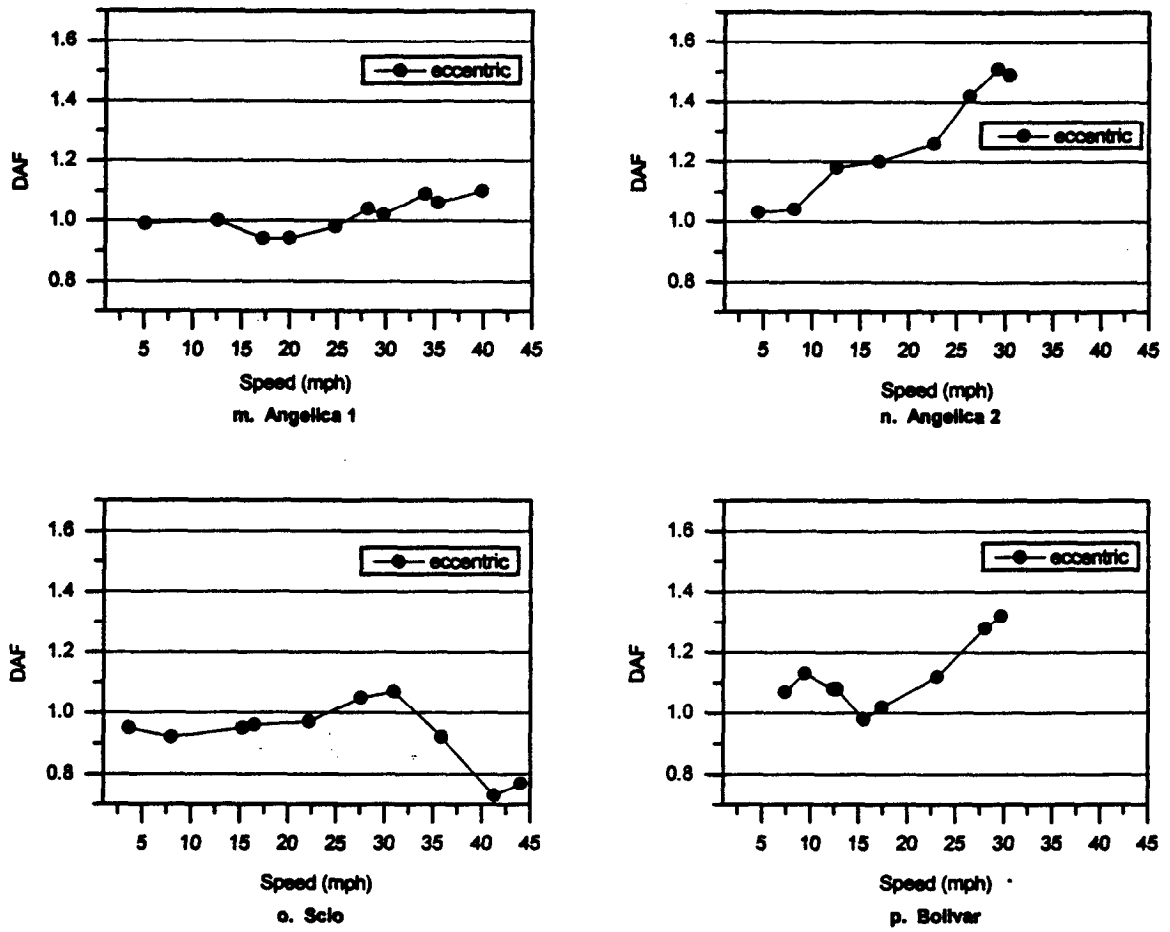


Figure 5 - Plots of in situ DAF (continued).

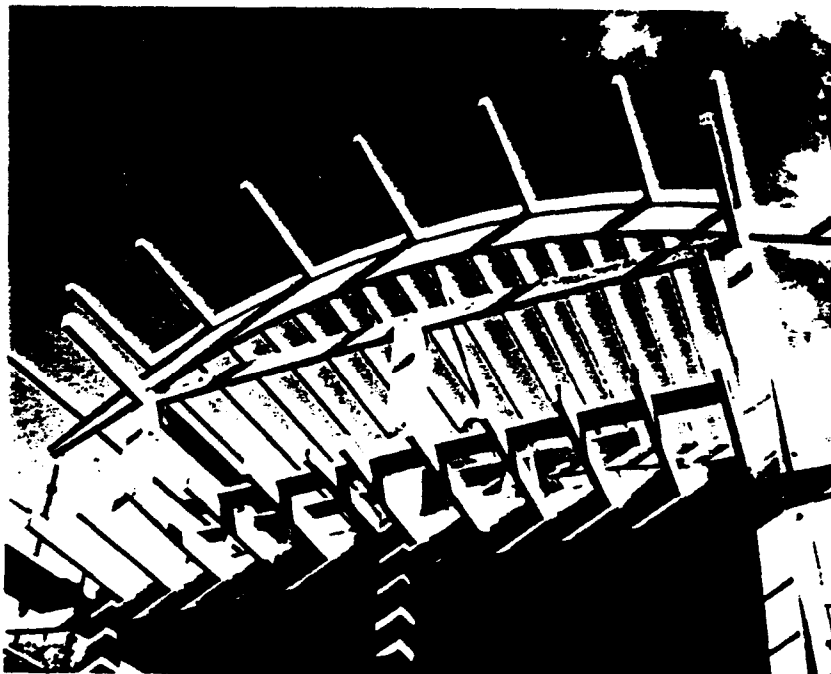


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