Load Testing of Temporary Structural Platforms

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Abstract

Scaffolding planks are widely used in the construction field as temporary platform support for workmen and materials. These scaffolding planks undergo dynamic impacts daily due to the weight of people and materials dropped onto them. These dynamic loads are not taken into account by professional and trade organizations, engineers, contractors and workers. This includes the Occupational Safety and Health Administration (OSHA) Handbook, which only lists the static load limits. Therefore, a standardized dynamic load procedure was developed. Based on this procedure, an experiment is described, which can be used as a laboratory exercise for a course in strength of materials.

Introduction

In recent years, attention has been directed to the effects of dynamic loading on solid-sawn and composite wood planks. Interest has multiplied because the scaffold platform material is the weakest link of any temporary structure. Because current platform design is based on static loading,[1] this procedure does not consider normal platform usage. Common usage always includes application of dynamic loading, such as workers jumping, materials being dropped, or load handling equipment hitting the platform from a higher level. To reduce the current design factors of safety against failure, each occurrence must be addressed and evaluated to get a realistic design factor of safety.

A standardized dynamic load procedure needs[2] to be developed to estimate the potential effect of the dynamic loading. Therefore, an investigation was undertaken to (1) design and build a testing apparatus; (2) develop a standardized testing procedure; (3) determine the theoretical and actual dynamic results for solid–sawn and manufactured wood platform; (4) compare theoretical and actual static and dynamic loading results; and (5) develop dynamic loading criteria. The results from this investigation have recently been reported.[3] The experiment described here is based on these results, which are a combination of the work done by two engineering senior design teams and a senior project in the Department of Construction Technology. The objectives of this experiment are to: (1) introduce the student to the concept of dynamic loading, as compared to static loading, (2) demonstrate a method for determining dynamic loading, (3) compare theoretical and actual static and dynamic loading results, and (4) develop and recommend dynamic loading criteria. The faculty advisors involved with this work intend to introduce this experiment as part of the laboratory exercises in a strength of materials course.

Theory

Static Loading

Three Point Bend Test

For a rectangular solid material such as a scaffolding plank, a three point bend test can be used to determine the flexural modulus, or modulus of elasticity (MOE) in bending. The results from this test are plotted similarly to a stress-strain curve, with the deflection replacing strain. The MOE in bending is determined in the following manner. The maximum deflection of a plank for a given load is:[4]

$$Y_{max} = PS^3 / 48EI \qquad \text{Eq. 1}$$

where
Y_{max} = maximum deflection of plank at a given load
P = applied static load
S = supported span length
E = modulus of elasticity (MOE)
I = moment of inertia

The moment of inertia for a rectangular cross section is:[5]

$$I = wt^3/12 \qquad \text{Eq. 2}$$

where
w = plank width
t = plank thickness

Substituting into Eq. 1, gives:

$$Y_{max} = PS^3/4Ewt^3 \qquad \text{Eq. 3}$$

Solving for E:

$$E = PS^3/4wt^3Y_{max} \qquad \text{Eq. 4}$$

This final relationship can be used to determine the static MOE.

The above is the most typical method for finding the flexural modulus. Another way of determining this modulus is a vibration technique.[6] In this method the plank is simply supported at its ends and is loaded at mid-span. The natural frequency of vibration is used to find the bending MOE.

Vibration Analysis

The Static Testing Apparatus, Vibration Analysis Machine, made by DynaMOE^{tm} works as follows.[7] A board or panel is laid on a knife-edge support at one end, and a load cell at the other. By pressing the member down at mid-span and releasing it, the member vibrates vertically. The load cell senses the changing reaction force and the A/D card acquires the electronic signal. DynaMOE^{tm} software records the signals and analyses the decaying sine wave. The average recorded force is the average reaction force on the load cell, and hence is half the weight on the member. The frequency of the decaying sine wave is f. Given the member geometry, weight and frequency, the dynamic modulus of elasticity E_d is calculated. This measured E_d is a simpler way of determining bending MOE for grading purposes, or for quality assurance. The relationship between dynamic modulus of elasticity, E_d, and frequency, f, of a transversely vibrating prismatic member, simply supported at its ends, is:

$$E_d = f^2 W L^3 / 2.46 g I \qquad \text{Eq. 5}$$

where W = weight of the member
L = length of the member
I = moment of inertia about the axis perpendicular to vibrating direction
g = acceleration of gravity
and 2.46 = constant for simple end supports

Eq. 5 is valid for a prismatic member of uniform cross section, such as rectangular beams or panels, or I-joists. Due to the fact that there is some overhang to support the prismatic member, L in Eq. 5 is replaced by the span, S, between supports and W is multiplied by S/L to give the weight of the member between supports. This gives:

$$E_d = f^2 W S^4 / 2.46 g I L \qquad \text{Eq. 6}$$

If the member has a rectangular cross-section, with w = width and t = thickness or height, then:

$$E_d = f^2 \rho S^4 / 0.205 g t^2 \qquad \text{Eq. 7}$$

where ρ = weight per unit volume?

If E_d is in psi, S, t and L in inches, f in Hz and ρ in lb/in^3, then g is 386 in / sec^2.

While E_d is called the dynamic modulus of elasticity, its value should be similar to the usual three point bend test discussed previously. The word dynamic refers to the fact that the member is being vibrated. The initial load applied was done so in a static manner.

Dynamic Loading

During dynamic loading the beam will be considered to undergo impact loading. The following is taken from Jensen and Chenoweth.[8] Consider the simple beam in Fig. 1. The impact load W is allowed to fall freely onto the mid-span of the beam. The beam deflects an amount δ under this condition, as indicated in Fig. 1. This same deflection δ could be produced by a gradually applied load of sufficient magnitude. This load will be called the equivalent static load, P_{EQ}. Because the deflections and stresses under the equivalent load P_{EQ} are the same as those under the impact load W, the internal strain energies are the same. The external work done by the loads must also be the same.

$$W(h + d) = \frac{P_{EQ}}{2}\delta \qquad \text{Eq. 8}$$

Since the deflection of the beam is proportional to the load that produces that deflection:

$$\frac{P_{EQ}}{d} = \frac{W}{d_{ST}} \qquad \text{Eq. 9}$$

where δ_{ST} is the static deflection under a gradually applied load W (Fig. 1). Substituting the value of P_{EQ} from Eq. 8 gives:

$$W(h + d) = \frac{Wd^2}{2d_{ST}} \qquad \text{or} \qquad h + d = \frac{d^2}{2d_{ST}} \qquad \text{Eq. 10}$$

Rearranging gives:

$$\delta^2 - 2\delta_{ST}\delta = 2h\delta_{ST} \qquad \text{Eq. 11}$$

Completing the square yields:

$$\delta^2 - 2\delta_{ST}\delta + \delta_{ST}^2 = \delta_{ST}^2 + 2h\delta_{ST} \qquad \text{Eq. 12}$$

or

$$(d - d_{ST})^2 = d_{ST}^2 \left(1 + \frac{2h}{d_{ST}}\right) \qquad \text{Eq. 13}$$

Taking the square root of each side gives:

$$d - d_{ST} = d_{ST}\sqrt{1 + \frac{2h}{d_{ST}}}$$

or

$$d = d_{ST}\left(1 + \sqrt{1 + \frac{2h}{d_{ST}}}\right) \qquad \text{Eq. 14}$$

Thus the deflection δ under impact loading is considerably greater than the static deflection δ_{ST} for the same load gradually applied. The factor $1 + \sqrt{1 + (2h/d_{ST}}$ can be thought of as an impact factor, which always exceeds unity.

Since the stresses in a beam are proportional to the load that produces them:

$$s_{ST}/W = s/P_{EQ} \qquad \text{Eq. 15}$$

where s_{ST} is the stress due to the gradually applied load W and s is the stress due to the equivalent load P_{EQ}. From Eq. 9, $P_{EQ} = W(\delta/\delta_{ST})$. Substituting for P_{EQ} in Eq. 15:

$$s_{ST}/W = s\delta_{ST}/W\delta \quad \text{or} \quad s = s_{ST}(\delta/\delta_{ST}) \qquad \text{Eq. 16}$$

From Eq. 14, $\delta/\delta_{ST} = 1+\sqrt{1+(\frac{2h}{d_{ST}})}$. Hence:

$$s = (1+\sqrt{1+\frac{2h}{d_{ST}}})s_{ST} \qquad \text{Eq. 17}$$

The stress s under impact loading is, then, the impact factor multiplied by the stress s_{ST} under the same loading gradually applied, that is, the static load.

Equipment and Supplies

1. Static Testing Apparatus – Compression Tester
   In this case a Tinius Olsen machine was used.
2. Three point Test Assembly (used in conjunction with compression tester)
3. Static Testing Apparatus – Vibration Analysis Machine made by DynaMOE^{tm}
4. PC, equipped with a A/D board
5. Dynamic Testing Apparatus
6. Scaffolding Planks
   a. Solid Sawn Wood Plank
      i. Surface Finish - Rough and Dressed (surfaced 4 sides)
      ii. Types – Southern Yellow Pine and Douglas Fir
   b. Manufactured Wood Plank
      i. Veneer Type
         (a) Horizontal
         (b) Vertical
      ii. Suppliers
         (a) 3 Manufacturers

Testing Apparatus

Static:

A DynaMOE^{tm} test apparatus (Figs. 2-6), a vibration analysis machine, was used to determine plank weight and Modulus of Elasticity (MOE). This method allows determination of MOE using dynamic methods. A conventional three-point assembly (Fig. 7) was usually used to confirm the static MOE. A Tinius Olsen compression tester with a specially designed apparatus was used for the bend test (Fig. 8).

After dynamic testing was performed the three-point assembly was occasionally used to measure a change in MOE.

Dynamic:

A newly designed and built apparatus was used to measure the dynamic force (Fig. 9). The apparatus designed for plank testing consisted of a steel A-frame, a 250 lb steel weight, a ½ ton hoist, a quick release mechanism, plank supports, a fine fixed weight drop height adjuster, and weight guides. The quick release mechanism for releasing a fixed weight consisted of a 500 lb electromagnet and a DC power supply. The weight guides were made from two linear bearings running on two cold-rolled 1-inch diameter rounds. The fine height adjustment fixture was made from a 1-ton turnbuckle. The ½ ton hoist and the electromagnet were used to elevate the 250 lb weight. The electromagnet and the weight guides allowed for a "free-fall' impact at the center of the selected scaffolding plank. The plank was supported at the base of the A-frame. A load cell was installed at one end of the frame supports to measure the dynamic force applied to the plank. The actual dynamic load was captured on an attached digital peak meter.

Standardized Testing Procedures

Static Nondestructive Procedures:

1. set up and calibrate DynaMOE^{tm} test apparatus
2. measure plank dimensions and water content
3. vibrate plank; and
4. read and record MOE, plank weight and frequency.

Static destructive procedures:

1. set up and calibrate the combined Tinius Olsen test frame apparatus
2. measure plank dimensions
3. read and record plank applied loads at prescribed deflections; and
4. calculate MOE.

Dynamic procedures:

1. set up and calibrate the dynamic test apparatus
2. raise test weight
3. set test specimen in place
4. place and release weight at prescribed heights
5. read and record peak loads; and prescribed heights
6. repeat steps 2 thru 5 until failure of the specimen occurs.

Samples Tested

Test specimens included solid-sawn (rough and dressed), horizontally and vertically veneered planks. Solid-sawn planks were Southern Yellow Pine and Douglas Fir. Veneered planks were supplied by three manufacturers (Fig. 10). Sample variables were plank span, height, width, moisture content, stiffness and specific gravity.

Results and Discussion

Typical results are shown in Fig. 11, where the experimental dynamic loads are compared with the theoretical equivalent static loads. Table I summarizes the range of values obtained for different planks and shows that the ratios of experimental to theoretical loads varied from 1.1 to 2.4.

In addition, the following were found: (1) Manufactured wood planks have less variable stiffness characteristics then do solid-sawn scaffold planks; (2) Manufactured wood planks have a more predictable ultimate failure load range than do solid sawn planks; and (3) Laminated joints or laminated veneer placement in manufactured planks, like annular rings spacing, knot size and placement of solid sawn scaffold planks, proved to affect specimen dynamic resistance.

Dynamic Loading Criteria

Based on ratios of actual peak to theoretical load a safety factor of three is recommended to prevent failure.

Implementation

This newly designed experiment will be introduced into future materials testing laboratories in the Departments of Engineering and Construction Engineering Technology.

Summary

1. The student is introduced to the concept of dynamic loading.
2. A method for determining dynamic loading was demonstrated.
3. A comparison of equivalent static and actual dynamic loads was made.
4. A safety factor of at least 3 is recommended as the dynamic loading criteria.
5. This experiment will be incorporated into the laboratory component of a strength of materials course.

References

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Biographical Information

Harvey Abramowitz received a B.S. in Materials Science from the Henry Krumb School of Mines, School of Engineering and Applied Science, Columbia University. He completed M.S. and D.Eng.Sc. degrees from the same school in extractive metallurgy/mineral engineering. Prior to coming to Purdue University Calumet, he was a Research Engineer at Inland Steel Research Laboratories and Visiting Professor at the University of Missouri, Rolla. He recently was a Visiting Scholar at Northwestern University. Dr. Abramowitz is an Associate Professor of Mechanical Engineering and is responsible for the materials sciences, solid waste management , and freshman engineering design and orientation courses. Major areas of research include the treatment of waste streams for metal recovery, the cryogenic treatment of steels, and strength of composite structural materials.

Ralph Bennett III received his B.S. in Civil Engineering. from the Univ. of Wisconsin. He received an M.S. in Civil Eng. from the Illinois Inst. of Tech. He is a licensed PE in IN and IL. Prior to joining Purdue Univ. Calumet, he had a civil engineering career at Inland Steel Co. Prof. Bennett has held administrative and teaching positions at Purdue. While at Purdue, he has been a civil eng. consultant and an expert witness within the international community.

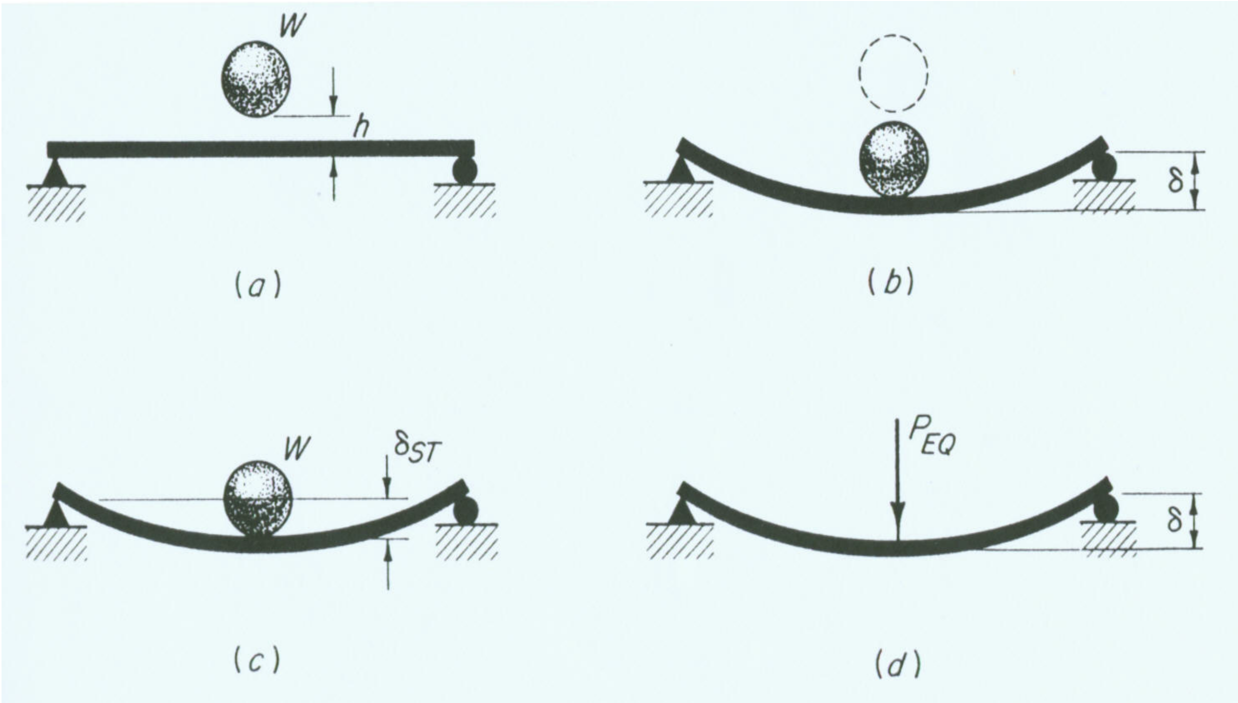

Fig. 1 Derivation of Impact Factor. (a) Impact load. (b) Deflection under impact load. (c) Deflection under gradually applied load *W*. (d) Equivalent gradually applied load to give some deflection as impact load *W*.

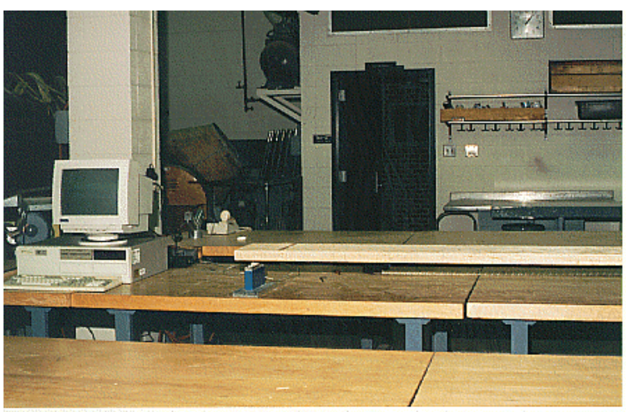

Fig. 2 Static Testing Apparatus - DynaMOE™

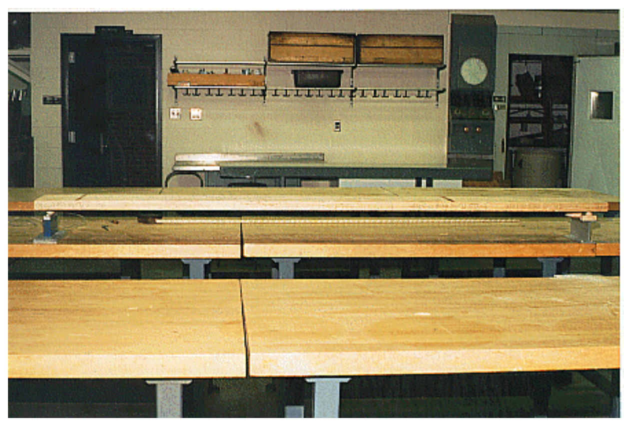

Fig. 3 Plank resting on support and load cell of DynaMOE™

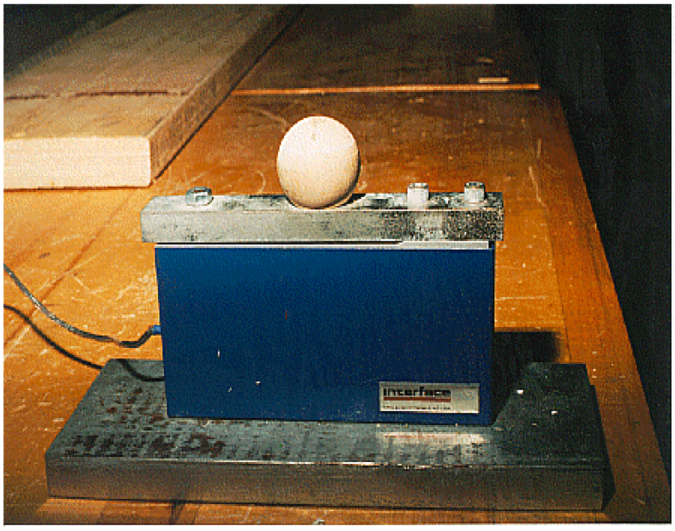

Fig. 4 DynaMOE™ Load Cell

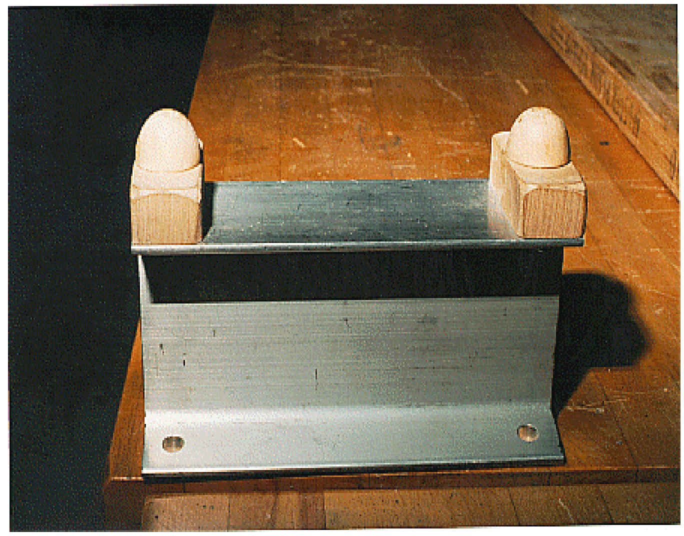

Fig. 5 DynaMOE™ Support

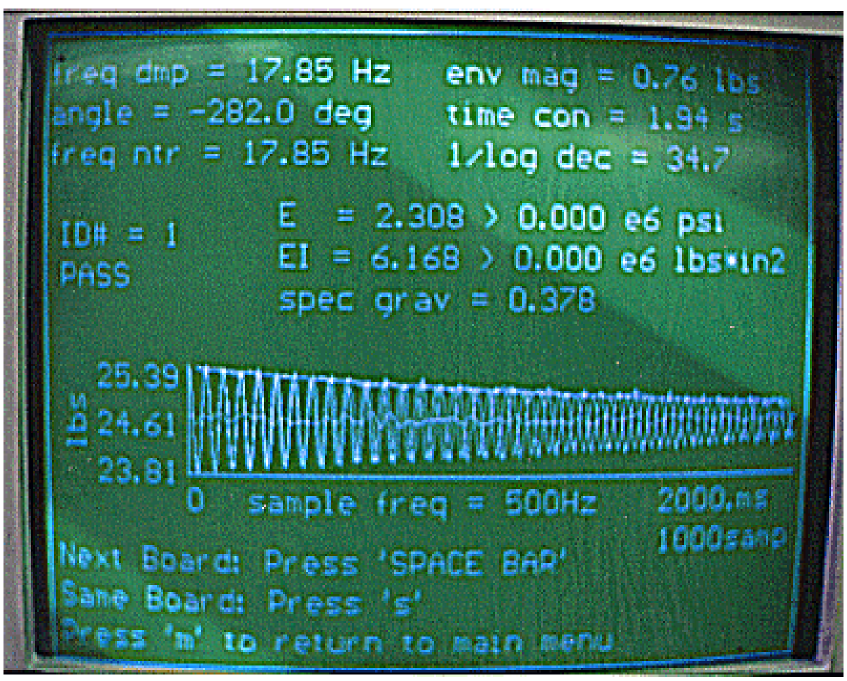

Fig. 6 Output from DynaMOE™ Test

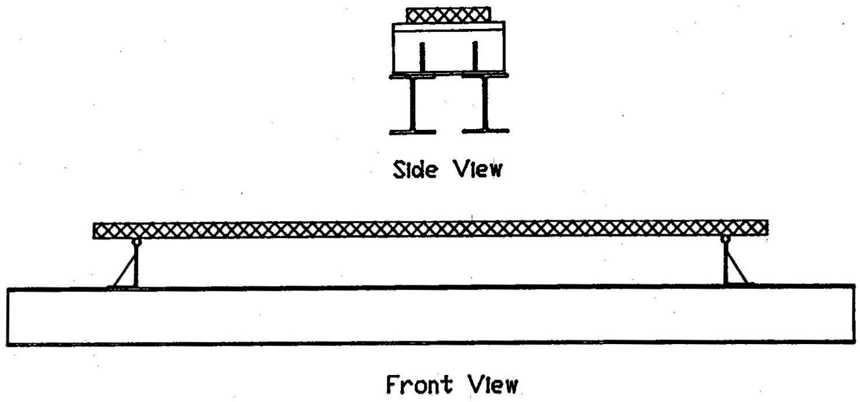

Fig. 7 Conventional Three Point Test Assembly

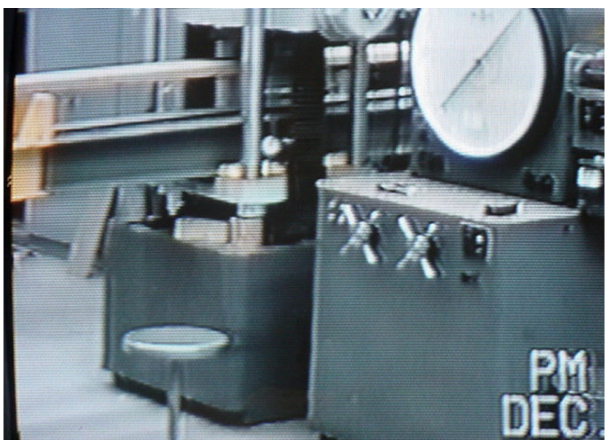

Fig. 8 Static Testing Apparatus – Tinius Olsen Testing Machine

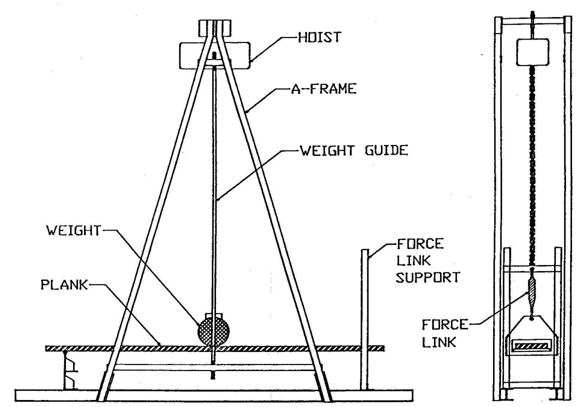

Fig. 9 Dynamic Testing Apparatus

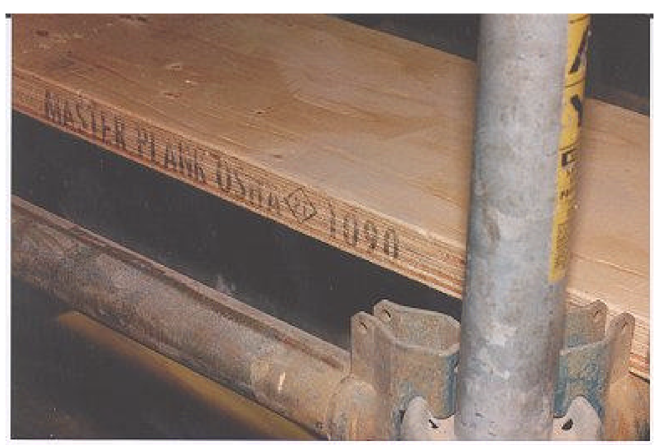

Fig. 10 Manufactured Wood Plank

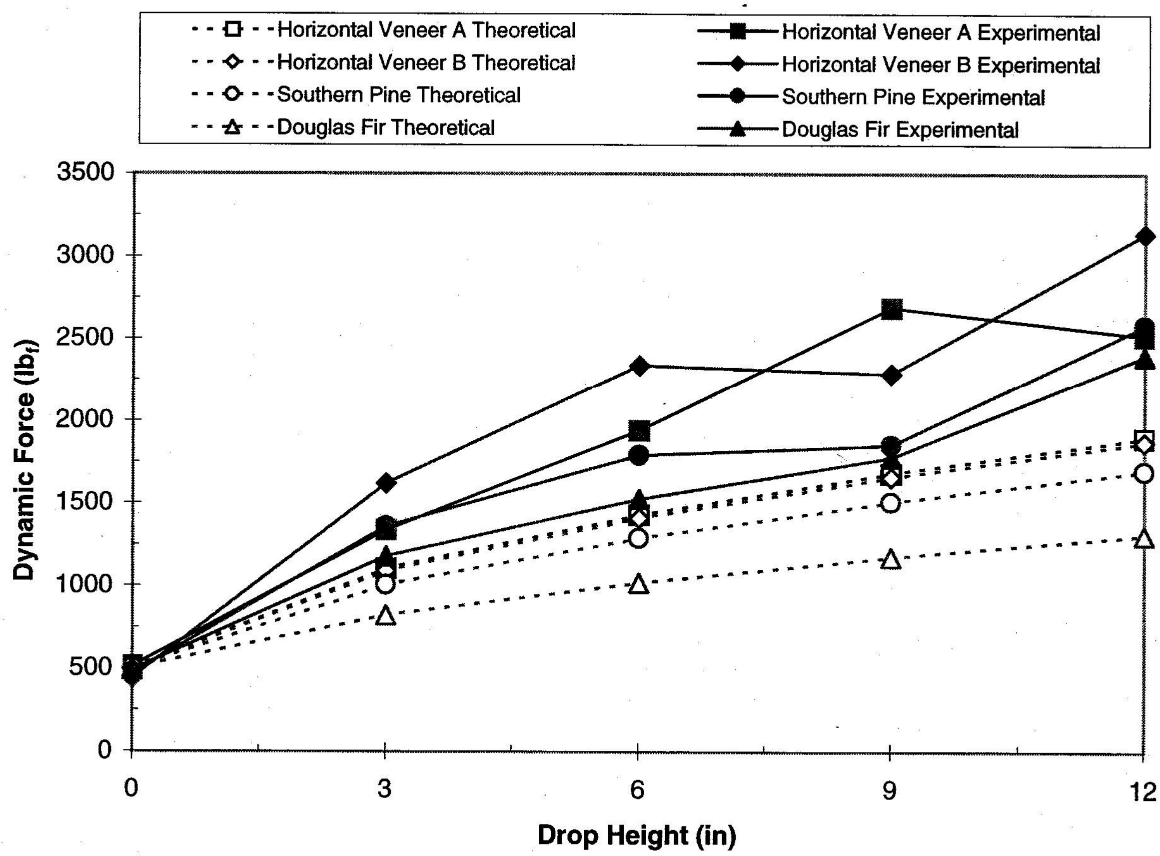

Fig. 11 Typical Dynamic Loading Results

TABLE I: DYNAMIC LOADING RESULTS

Plank	MOE Dynamic ($x10^6$psi)	MOE Static ($x10^6$psi)	Density (lb_m/in^3)	Moisture Content (%)	Ratio Experimental/ Theoretical
Southern Pine	1.50-3.00	2.02-2.80	.020-.029	10.00-13.00	1.41-2.21
Douglas Fir	1.75-2.60	ND	ND	11.00-12.50	1.51-2.67
Horizontal Veneer A	1.97-2.35	ND	.024-.026	12.50-16.50	1.52-1.88
Horizontal Veneer B	1.90-1.99	1.872-2.050	0.019	14.50-16.00	1.22-1.60
Vertical Veneer	1.75-2.42	1.975-2.403	.021-.026	9.25-12.75	1.40-1.65

ND: Not Determined

Thickness 1.50-1.63 in
Width 9.06-11.75 in
Length 96.00-145.13 in