APPENDIX. REFERENCES

Tingley, D. A. (1994a). "Aligned fiber reinforcement panel for structural wood members." *U.S. Patent Document No. 5,262,545*, U.S. Patent Ofc., Washington, D.C.

Tingley, D. A. (1994b). "Glued-laminated beams having a high-strength fiber-reinforcement: the bi-material interface." *Proc., Int. Timber Engrg. Conf.*

Tingley, D. A. (1994) "The stress distribution through the depth of a beam reinforced with high-strength reinforced plastic," PhD dissertation, Oregon State Univ., Corvallis, Oreg.

Tingley, D. A. (1994d). "Wood and wood composite design using high-strength fiber-reinforced plastic (FiRP Panel) with special emphasis on glued laminated beam bridges." *Proc., 4th Int. Conf. on Short and Medium Span Bridges*, 947–958.

Closure by Nikolaos Plevris[4] Associate Member, ASCE, and Thanasis C. Triantafillou,[5] Member, ASCE

The writers wish to thank the discusser for his interest in the paper. The points raised by the discusser are addressed in the order he presented them.

MATERIAL CONSTITUTIVE LAWS

The quite common assumption made in the paper is that wood is characterized by the same modulus of elasticity in both tension and compression. Its value is obtained from bending tests, and it can be thought of as an "average" one, which is different from the individual moduli by not more than 2–3%. On the other hand, the model parameters given in (1)–(16) are calibrated from bending tests too, which makes the whole procedure followed here for the prediction of creep in wood beams consistent, and so $E_{eff}(t)$ defined by (18) is not affected by the difference between tension and compression.

ANALYSIS OF CROSS SECTIONS

Shrinkage in the transverse direction has not been considered in the model. It should be remembered that the analytical model presented in the paper refers to creep-related phenomena, that is to serviceability limit states, and thus failure of the FRP-wood interface (a strength limit state) has been considered of no relevance. The same comment applies to the discusser's point regarding contraction-induced stresses, which can be studied independently (and are far from the scope of this study).

PARAMETRIC STUDIES

The AFRP used is low modulus, indeed. The authors agree with the discusser that high modulus aramid has better creep characteristics than the low modulus one. However, these characteristics are by no means better than those of glass. The relatively poor creep performance of AFRP, even high modulus, has been demonstrated by various researchers [e.g., Imperial College (1988), Phillips (1989)].

We disagree with the discusser's point that the dependence of FRP creep strains on stress level has not been considered in the paper. A better examination of (21) shows exactly this dependence [σ in (21) is the applied stress, and m is also a function of stress]. A similar argument holds for moisture effects on the creep response of FRPs. In the analytical formulation, these effects can be taken into account through the material constants E_0 and n. But since the effect of moisture on the viscoelastic moduli of unidirectional composities is not significant (as it may be on the strength under sustained loads), it has not been considered in the parametric study.

Consideration of FRP debonding is a strength limit state, and its study lies outside the scope of the paper. Strength limit states analyses for FRP-reinforced wood can be found in Plevris and Triantafillou (1992).

The meaning of the authors' statement that "creep behavior of FRP-reinforced wood is primarily dominated by creep in wood" is that creep-related phenomena (such as curvatures) are caused primarily because wood creeps a lot more than FRPs. In other words, the largest portion of creep (curvature, for instance) is due to creep of wood, regardless of the type of FRP used as reinforcement. The comments by the discusser with regard to the increase of FRP stress levels, the modular ratio of FRP compared to wood, and that FRP will tend to control deflections are all valid and present nothing new; they have all been presented in the paper and are clearly illustrated, for instance, in Fig. 7(a) and 10(a) of the paper.

APPENDIX. REFERENCE

Imperial College of Science and Technology. (1988). *Proc., Symp. on Engrg. Appl. of Parafil Ropes*, London, England.

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PERFORMANCE OF MULTIPLE MASS DAMPERS UNDER RANDOM LOADING[a]

Discussion by Patricio A. A. Laura[3]

The authors are to be congratulated for their interesting and very practical results. Some additional references on the subject may be useful to the interested reader.

The feasibility of implementing two dynamic vibration absorbers was first explored by Snowdon and coworkers (Snowdon and Nobile 1980; Snowdon et al. 1984). They proposed the "cruciform dynamic absorber," which comprises two beam-like dynamic absorbers attached to one another at right angles at their midpoints. One of its branches (arms) can be tuned to suppress the fundamental resonance of the system, while the other can be tuned to suppress the second or third resonances or to lower the transmissibility at any higher troublesome resonance.

The possibility of implementing two mass dampers in the case of a machine foundation excited at its translational and rotational fundamental modes was successfully investigated by Pombo and Laura (1986).

APPENDIX. REFERENCES

Pombo, J. L., and Laura, P. A. A. (1986). "Use of two dynamic vibration absorbers in the case of machinery operating at two frequencies which coincide with two natural frequencies of the system." *Appl. Acoustics* 19, 41–45.

Snowdon, J. C., and Nobile, M. A. (1980). "Beam-like dynamic vibration absorbers." *Acustica*, 44, 99–108.

[a]February 1995, Vol. 121, No. 2, by Ahsan Kareem and Samuel Kline (Paper 7595).

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Snowdon, J. C., Wolfe, A. A., and Kerlin, R. L. (1984). "The cruciform dynamic vibration absorber." *J. Acoustic Soc. Am.*, 75, 1792–1799.

Closure by Ahsan Kareem[4] and Samuel Kline[5]

The writers would like to thank the discusser for his interest in the paper. We certainly welcome the additional references related to our work provided in the discussion. Our work primarily addressed the application of dampers to civil engineering structures. In this context, we had indicated that multiple dampers can be configured in a series or a parallel arrangement. These can be incorporated in a structural system at one location or distributed spatially. The effectiveness of multiple dampers, spatially distributed in a structure, was investigated by Kareem and Sun (1987). Bergman et al. (1989, 1991), Subardjo et al. (1992) and others. The analysis suggested that the damper tuned to the fundamental mode is most effective and other strategically located dampers, tuned to higher modes, facilitate improved performance. The discussion has provided examples of multiple dampers used to control machinery vibrations.

The type of multiple dampers studied in our paper is different from the aforementioned ones. The analysis in this paper concerns multiple mass dampers in which the natural frequencies of the dampers are distributed over a range of frequencies. The total mass of these smaller dampers is equal to the mass typically used for a single damper. These dampers are more effective under excitation frequencies distributed over a wider band. Such units can be placed at appropriate locations to control different modes of vibration.

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EBEF Method for Distortional Analysis of Steel Box Girder Bridges[a]

Discussion by Víctor H. Cortínez[4] and Marcelo T. Piován[5]

INTRODUCTION

In their paper, the authors have proposed the EBEF method for the distortional analysis of box girder bridges.

It consists fundamentally in the use of the analogy between the beam on elastic foundation (BEF) and the distortional analysis of box girders.

While the traditional BEF analysis is based on the Fourier series solution, the EBEF method uses a finite-element (FE) formulation.

The FE developed by the authors takes into account the shear effect [Timoshenko's (1956) theory] providing the Bermoulli Euler BEF as a particular case.

The EBEF method, as the authors have pointed out, is more versatile than the traditional one because it can be applied with great simplicity to more complex problems such as varied sections and multispan beams.

The purpose of the current discussion is to present an alternative FE, based on the exact solution, that may be more convenient, for some situations, than the authors' approach.

To develop the present element, the shear effect is neglected.

EXACT FE

Consider an element of length of l_e with constant values of EI_e and k_e, subjected to an arbitrary loading $p(x)$. The governing differential equation [(1) of the authors] may be written in dimensionless form as

$$\frac{d^4\eta}{ds^4} + 4\xi^4\eta = \frac{p(s)l_e^4}{EI_e} \tag{67}$$

where $s = x/l_e\varepsilon(0, 1)$; and $\xi^4 = kl_e^4/(4EI_e)$. Subjected to the boundary conditions (Fig. 11)

$$\eta(0) = q_1, \frac{1}{l_e}\frac{d\eta}{ds}(0) = q_2, \eta(1) = q_3, \frac{1}{l_e}\frac{d\eta}{ds}(1) = q_4 \tag{68}$$

where q_i = nodal generalized displacements.

The general solution can be expressed as

$$\eta = v_1 + v_2 \tag{69}$$

where v_2 = a particular integral of (67) satisfying

$$v_2(0) = dv_2/ds(0) = v_2(1) = dv_2/ds(1) = 0 \tag{70}$$

and v_1 = complementary solution of (67) (with $p = 0$) given by

$$v_1(s) = C_1e^{\xi s}\cos(\xi s) + C_2e^{\xi s}\sin(\xi s) + C_3e^{-\xi s}\cos(\xi s) + C_4e^{-\xi s}\sin(\xi s) = \sum_{i=1}^{4} C_iF_i(s) \tag{71}$$

The C_i constants are to be determined in such a way that v_1 and then η verifies conditions (68).

Accordingly, by substituting (71) in (68) an algebraic linear system is obtained, which may be symbolized as

$$\sum A_{ij}C_j = q_i \tag{72}$$

By solving (72) for the C_is and replacing in (71) one arrives at

$$v_1 = \sum_{i=1}^{4} N_i(s)q_i \tag{73}$$

where

$$N_i = \sum_{i=1}^{4} F_i(s)\alpha_{itj}; \quad [\alpha_{ij}] = [A_{ij}]^{-1} \tag{74a,b}$$

The governing energy functional of the element is given by

$$J_e = \frac{EI_e}{2l_e}\int_0^1 \left(\frac{d^2\eta}{ds^2}\right)^2 ds + \frac{kl_e}{2}\int_0^1 \eta^2\, ds - l_e\int_0^1 p(s)\eta\, ds \tag{75}$$

By using (69) and reordering this last expression may be written as

[a]March 1995, Vol. 121, No. 3, by Yao T. Hsu, C. C. Fu, and David R. Schelling (Paper 27054).

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