Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 173 (2017) 391 – 396

Procedia Engineering

www.elsevier.com/locate/procedia

11th International Symposium on Plasticity and Impact Mechanics, Implast 2016

Scaling and structural impact

Marcílio Alves*, R.E. Oshiro, M.A.G. Calle and L.M. Mazzariol

Group of Solid Mechanics and Structural Impact
University of São Paulo, maralves@usp.br
Av Prof Mello Moraes 2231 São Paulo, 05508900, Brazil

Abstract

Experiments dealing with impact of large structures, like ships and buses, are cost prohibitive. One possibility is to test scaled models, which unfortunately do not obey the scaling laws due to material strain rate sensitivity. A set of scaling numbers is here presented that allow perfect similarity between model and strain rate sensitive prototypes. It is shown how nonscaled models can be used to predict the prototype behavior. As a complement, it is commented on recent developments of new scaling laws that allow model and prototype with different densities to be directly compared.

Peer-review under responsibility of the organizing committee of Implast 2016

Keywords: scaling; structural impact; experimental mechanics

1. Introduction

Scaling of structures means to reproduce in small size a real large structure. This small size structure is similar to the real actual object of analysis and it can be conveniently handled for tests and measurements. It is also possible to reproduce in a large size a structure that it is too small to be tested, although this is less common. The actual structure is the prototype, *p*, and the small structure model, *m*, so that the scaling factor, β, for a given variable, say length, is

---

* Corresponding author.
E-mail address: maralves@usp.br

Peer-review under responsibility of the organizing committee of Implast 2016
doi:10.1016/j.proeng.2016.12.036

$$\beta = \frac{L_m}{L_p} \tag{1}$$

The subject of scaling was mainly explored in the context of fluid mechanics and it has been used for studies on fluid flow around complex geometries. In the structural area, Ref. [1] presents the basic equations that relate the various mechanical variables to the scaling factors, as listed in Table 1.

Table 1. Scaling factor relation for variables of an impact analysis.

variable	scaling factor	variable	scaling factor
length	β	wave velocity	1
displacement	β	time	β
mass	β^3	velocity	1
strain	1	strain rate	$1/\beta$
stress	1	acceleration	$1/\beta$

It can be noticed from Table 1 that the stress in a model is the same as the stress in the respective prototype. However, when the stress is increased by the material strain rate sensitivity, as described, for instance, by the Norton-Hoff law.

$$\sigma_d = \sigma_0 \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right)^q , \tag{2}$$

where σ_0 is quasi-static flow stress, $\dot{\varepsilon}_0$ is the corresponding strain rate at σ_0 and q is a material constant, it can be easily shown that the stress in the model and in the prototype will be a function of β, so contradicting Table 1.

Ref. [2] suggests a way round this problem by working with a new basis of variables. Instead of the traditional mass *M*, length, *L*, and time, *T*, the authors adopted the initial velocity, V_0, dynamic yielding stress, σ_d, and impact mass, G, being then generated the dimensionless numbers, Π,

$$\underbrace{\left[\frac{A^3 G}{V_0^4 \sigma_d}\right]}_{\Pi_1}, \underbrace{\left[\frac{t^3 \sigma_d V_0}{G}\right]}_{\Pi_2}, \underbrace{\left[\frac{\delta^3 \sigma_d}{G V_0^2}\right]}_{\Pi_3}, \underbrace{\left[\dot{\varepsilon}\left(\frac{G}{\sigma_d V_0}\right)^{1/3}\right]}_{\Pi_4}, \underbrace{\left[\frac{\sigma}{\sigma_d}\right]}_{\Pi_5}$$

from which the factors $\beta_{\dot{\varepsilon}}$, β_t, β_A and β_σ are written in terms of β and β_V, as follows

$$\beta_{\sigma_d} = \beta_V^{\ 2} \tag{3}$$

$$\beta_{\dot{\varepsilon}} = \frac{\beta_V}{\beta} \tag{4}$$

$$\beta_t = \frac{\beta}{\beta_V} \tag{5}$$