SCALE-MODEL TESTING OF SOIL-VEHICLE SYSTEMS

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Abstract. Full-scale testing of vehicles is notoriously difficult and expensive. Invariably only a small range of vehicle configurations and soil conditions can be explored and it is difficult to ensure consistency and uniformity of terrain. Scale-model testing may provide a more versatile and cost-effective method for exploring the behaviour of off-road vehicles. This paper describes some of the simple rules which have to be observed when modelling vehicle operations on soil and presents results from three case studies of scale-model tests on tracked vehicles and earth anchors carried out in soil bins at The Royal Military College of Science (RMCS) in the United Kingdom. The results are shown to correlate well with theoretical predictions of full-scale performance and with empirical predictions based on full-scale trials.

INTRODUCTION

One of the major inhibitors of progress in the field of terramechanics has been the complexity and cost of conducting full-scale trials. Such trials are invariably specific to a particular vehicle configuration and terrain type and are often subject to variability in the ground conditions, local topography and weather. Moreover it is very difficult to vary the physical properties of the running gear in order to explore the impact of, say, track breadth or suspension stiffness on mobilisable draw-bar-pull (DBP).

This paper describes a number of investigations into soil-vehicle interaction conducted by the author in the Mobility Laboratory at The Royal Military College of Science, Shrivenham (RMCS), UK. The paper argues that such model tests offer a number of advantages. These include very effective control of the soil conditions and the ease with which geometry and loads can be changed at minimal cost. Hopefully it will not rain in the laboratory, nor will the local farmer come along and plough up the test track part way through the trials programme. On the other hand, a scale-model test is just a scale-model test. At some stage in the work, it will need some degree of validation at full scale.

THEORY

The scaling of soil-vehicle interaction was examined in some detail by Schuring [1]. This provides a viable basis for investigations at model scale. Such investigations could yield, for example, information on the resistive force which could be mobilised by an anchor, the draught force on a plough or the draw-bar-pull which could be generated by a main battle tank. In fact force estimation is often the focus of such studies. A useful dimensionless parameter (or π group) which is often adopted in scaling work is therefore:

$$\frac{F}{\gamma l^3} \qquad (1)$$

in which:

- F is a characteristic force (such as draw-bar-pull);
- γ is the bulk unit weight of the soil (that is, density × g); and
- l is a characteristic length (such as blade height or track width).

Dimensional analysis is based on the concept that this π group is a function of a set of other dimensionless groups. The key to successful scaling of any physical system is the correct identification of the salient parameters which govern the physical process. These, too, are combined into dimensionless π groups. Our force π group (Equation (1)) is now a function of the other assembled π groups:

$$\frac{F}{\gamma l^3} = f\{\pi_1\ ,\pi_2\ ,\pi_3 ....\} \qquad (2)$$

The scaling law can now be stated as follows:

> *If the value of each of the π groups on the right hand side of Equation (2) takes the same value at full and model scale, the value of the force π group on the left hand side of Equation (2) will also take the same value at full and model scale.*

The scaling process is therefore quite straightforward provided no conflicts arise from the requirement to keep all of the π group values the same at model and full scale. In the case of soil-vehicle interaction, a conflict can arise if the forces generated are affected by the speed of the process. However, some processes are very slow (such as anchoring) or are relatively insensitive to speed. By excluding speed from the analysis and with some careful manipulation of soil properties, effective and successful scale modelling can usually be achieved.

CASE STUDY 1—EARTH ANCHORS

During the 1980s, the author carried out design calculations for earth anchors for both Challenger Armoured Repair and Recovery Vehicle and for the Recovery variant of Warrior. In each case, it was deemed desirable to carry out tests at model scale to confirm that the anchors would meet the stated requirement.

In each case the requirement was stated in terms of the resistive force which could be generated by the blades when fully dug in to soils with certain specified shear strength properties. These included a saturated clay, a dry sand and a ‘typical top soil’.

On the assumption that the anchoring process was, essentially, quasi-static, the following π groups were identified:

$$\frac{F}{\gamma l^3} = f\left\{\beta,\phi,\delta,\frac{c}{\gamma l},\frac{a}{\gamma l},\frac{q}{\gamma l}\right\} \qquad (3)$$

where:

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