THE PERFORMANCE OF BIAXIAL GEOGRIDS UNDER A ROLLING WHEEL AND THE INFLUENCE OF DIRECTIONALITY

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Abstract: Geogrids in mechanically stabilised aggregate layers are, traditionally, biaxial in nature. As a reflection of the various manufacturing methods, the tensile elements are arranged in a longitudinal or machine direction (MD), and a transverse or cross machine direction, (CMD). The resulting apertures of a biaxial geogrid are rectangular in form and the physical quality control properties of strength and associated strain is reported in these orthogonal directions. It is normally the case that, in the installation of geogrids in road applications, the longitudinal and transverse directions are aligned as such in the road. Fortunately, the various rigidity and stiffness properties of a geogrid, which contribute to the performance of a mechanically stabilised layer, are arranged in an appropriate sense in a road with its, predominantly, linear traffic loading. Necessarily, product innovation has to be unbridled by such convention and progress can come about by seeking to improve performance under dynamic loading, (i.e. traffic) in pavements.

In three-dimensional cases of mechanical stabilisation of aggregate layers, the an-isotropic properties of a biaxial geogrid have been found to be an important influence on performance under traffic loading that is not aligned to the geogrid's longitudinal or transverse directions. That is, laboratory testing of traffic passing in a diagonal direction across a geogrid shows that the performance is below that of traffic passing in the orthogonal directions. For geogrids that are to be installed in facilities, such as a hardstanding, a parking area or in a pavement for yards, docks, taxiways and the like, this finding is significant. It could indicate that, in such geogrid applications, with their more random trafficking patterns, the geosynthetic reinforcement may not perform as well as has been assumed in some design models in current use. The paper provides the findings of the laboratory work, with respect to the direction of a rolling wheel load and suggests the case for geogrids with more isotropic properties.

Keywords: biaxial geogrids, interlock, rutting, stabilisation, stiffness, tensile strength

INTRODUCTION

Geogrids in mechanically stabilised aggregate layers are, normally, biaxial in nature. As a reflection of the various manufacturing methods, such as monolithic stretching, and latterly weaving and welding, the tensile elements are arranged in a longitudinal or machine direction (MD), and also a transverse or cross machine direction, (CMD). The resulting apertures of a biaxial geogrid are rectangular in form, as shown in Figure 1.

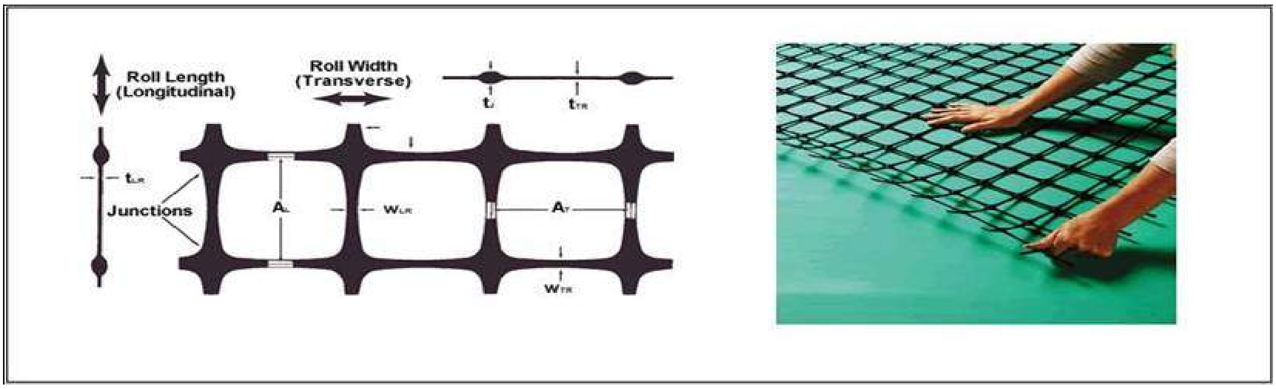

Figure 1. The geometry of a geogrid: ribs, junctions and the resulting apertures

The manufacturing methods employed in geogrid production will bestow the various physical and mechanical properties and characteristics of that particular type of geogrid. Such properties and characteristics will govern the performance of a geogrid in a mechanically stabilised layer in ground stabilisation works.

Considering the common case where a mechanically stabilised layer is to be subjected to traffic load, then the capturing of its performance is achieved by either conducting full scale trafficking test, having an accurate mechanistic model or adopting a hypothetical analytical model. The three approaches are illustrated in Figure 2. They can be regarded as complementary in the devising of design tools.

Figure 2(a). Full scale trafficking testing for an empirical model

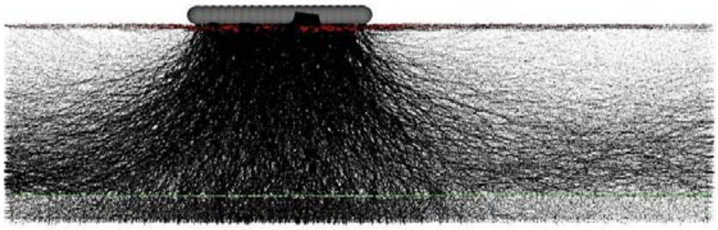

Figure 2(b). Mechanistic model

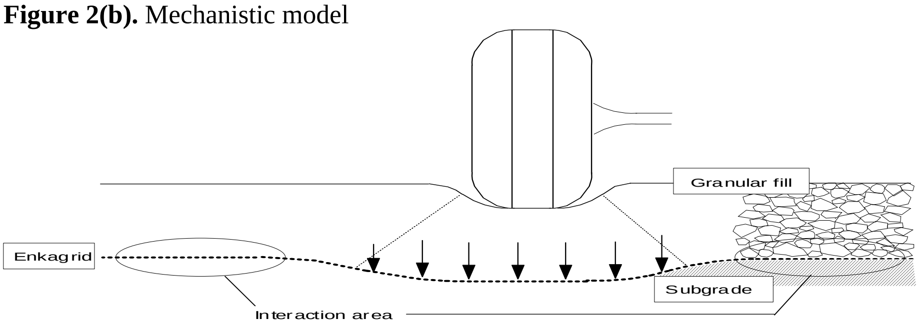

Figure 2(c). Hypothetical model, © Colbond Geosynthetics

Considering the first of these approaches in determining the performance of a mechanically stabilised layer, rolling wheel testing has proved to be a reliable way to determine the effect of a geogrid compared with an unstabilised control layer in similar conditions and under similar loading (Watts 2004). The data is collected and usually presented as a 'surface deformation v number of wheel passes' chart. In addition, in the deconstruction of the test programme, the test bay can be 'trenched'. The excavation of a cross-sectional trench provides the opportunity to examine the deformation profile of the full layer and deduce the stabilisation mechanism that has operated and having been responsible for the measured 'deformation v traffic' performance, as shown in Figure 3.

The two commonly recognised stabilisation mechanisms have been observed in the past (Watts 2004) and are depicted in Figure 3: these are described as the confinement, (left), tensioned membrane, (right), effects. The confinement and tensioned membrane effects, (hence reinforcement mechanisms), are illustrated in Figure 4. The confinement effect relies heavily on the interlock phenomenon being set up and providing a response to loading. There is a generation of a shear restraint at the underside of the aggregate layer - as deformation occurs there is a controlled accumulation of strains. Efficient stabilisation is achieved if the horizontal strains are significantly reduced when compared with an unstabilised control. The tensioned membrane effect requires the aggregate/subgrade interface to be deformed by the loading and to generate tension in the membrane when further load is applied over the mid-point of the deformation. The vertical component of the membrane tension then offers a reaction to the load.

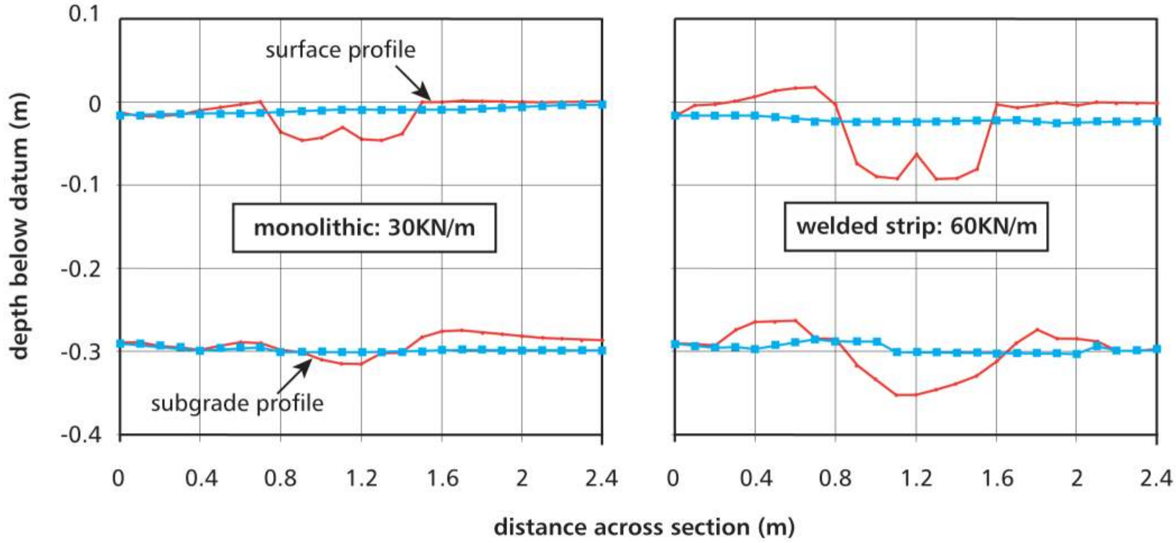

Figure 3. Deformation profiles indication difference responses to rolling wheel loading

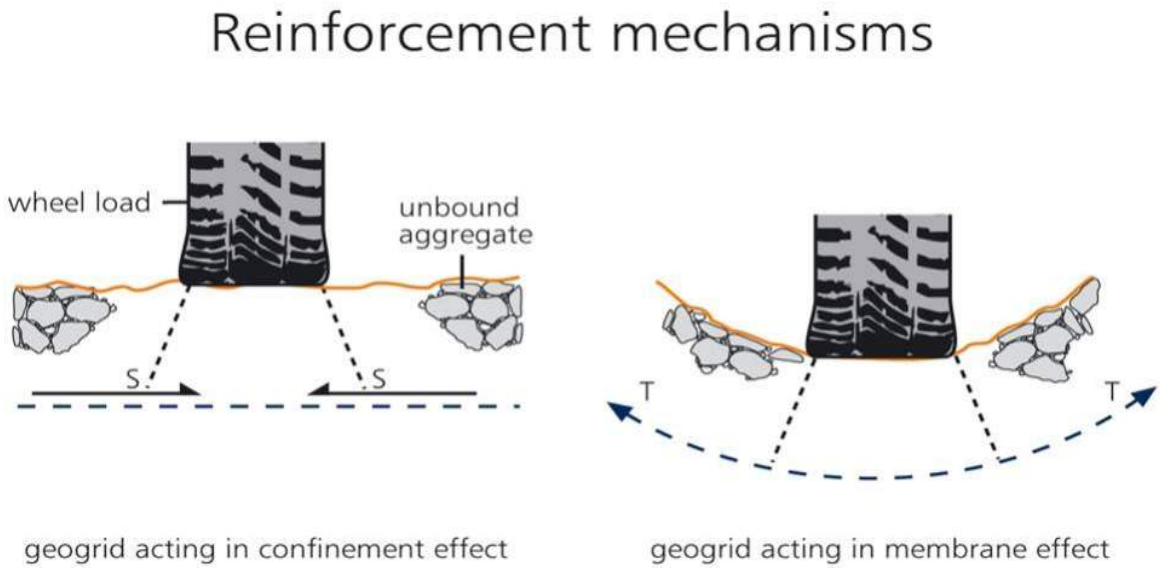

Figure 4. The two common stabilisation mechanisms

To date, these concepts, models and design methods have one thing in common. That is that the visualisation of the stabilisation effects in the cross section only, (such as Figure 4). In practice this means selecting the transverse section of a road and employing the properties in the cross-machine direction of the installed geogrid. These have been considered to be sufficient to encompass and describe the response to load.

But stabilisation is a three-dimensional phenomenon. The load distribution from an applied wheel load, through the aggregate layer, is radial in nature. The load distribution is conical. A question therefore arises on whether a geogrid, with its orthogonal rib arrangement, will provide the performance that is assumed or derived from its orthogonal strength properties. The question goes further when considering the hypothetical models, such as the tensioned membrane effect. This effect requires not only trafficking in an orthogonal direction but also, highly channelised traffic that is constantly applied to the mid-point of the deformation profile, (Giroud 2006).

In practice, especially in the stabilisation of large and often rectangular areas, the traffic patterns and the rolling wheel loading are less predictable. So, what implications are there, for the performance of mechanically stabilised layers, for traffic directions that are not aligned to the orthogonal rib alignments of the geogrid? The paper describes an investigation of this question.

DESCRIPTION

In 2006, a test program was conducted on the so called 'slab tester' at the University of Nottingham, UK. This equipment, shown in Figure 5, has provided reliable results, over many years, from a rolling wheel loading on pavement elements.

Figure 5. University of Nottingham slab testing equipment

The test procedure has been carefully established and, with care, this equipment can indicate quite subtle differences and variations in the geogrid inclusions. The test materials are a clay subgrade, a graded granular aggregate and a geogrid at the interface. The parameters for the test are given in Table 1.

Table 1. Test parameters and conditions

Property	Value	Accuracy
Apparatus		
Box length	1000mm	-
Box width	600mm	-
Materials		
Clay moisture content	23%	±1%
Cone penetrometer value[1]	6.5	±0.5
Clay depth	70mm	±1mm
Sub-base specification	UK HA Type 1	
Sub-base moisture content	3%	±2%
Sub-base depth	135mm	±5mm
Loading		
Wheel tyre pressure	45 psi	±1 psi
Wheel tyre width	110mm	-
Wheel tyre load	2 kN	±0.1 kN
Wheel tyre speed	20 passes/min	±1/min
Inputs	Unit	Accuracy
Geogrid type	-	-
Geogrid orientation	degree	±2º
Outputs		
Number of wheel passes	number	±500
Wheel path deformation	mm	±0.5mm
Notes 1. in-house device for determining consistency		

In arriving at the test procedure, a range of trials were carried out to determine and fix such factors as:

- clay source
- clay condition
- clay strength v moisture content calibration
- clay depth
- sub-base condition
- sub-base thickness
- loading specification
- output measurement – accuracy and sensitivity
- installation and set up

The purpose of the trafficking tests was to investigate whether the direction of trafficking had a significant effect on the performance of the mechanically stabilised layer. This paper describes a series of tests that were carried out on a monolithic geogrid of the type that is manufactured from the punching and biaxial stretching of an extruded sheet, as characteristically shown in Figure 1. This geogrid is orthogonally regular with square apertures and similar geometry and tensile stiffness in the MD and CMD directions.

RESULTS

In view of the orthogonal regularity of the geogrid, two traffic directions were investigated; these were the MD and MD+45º directions. The result is shown in Figure 5.

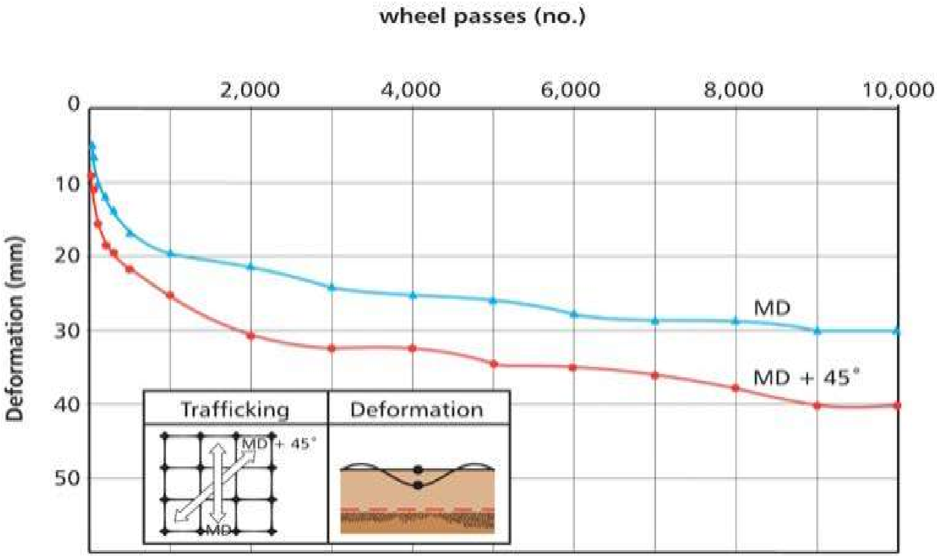

Figure 6. Plot of deformation against wheel passes

DISCUSSION 1

Figure 6 displays the usual form of deformation v wheel passes curve. The design of such tests is to achieve several thousand wheel passes with surface deformations not exceeding 40mm: this aim has been achieved here. It is also common to have a rapid build-up of deformation at a low number of passes and then for the curves to flatten out.

Towards the end of the tests, the difference in the deformation for the two orientations is around 10mm. For a reference deformation of 30mm, the long term traffic improvement factor is around 4.5.

The two values quoted above, (10mm difference in deformation and a traffic improvement factor of around 4.5 as the surface deformation becomes developed), are significant. They indicate that traffic orientation is an important influence on performance. Put simply, performance is reduced when the traffic orientation is 'across the diagonal' rather than aligned with an orthogonal. This result indicates that the hypothetical analytical design models that employ only CMD, or MD, geogrid properties and that assume, thereby, that deformations are countered by orthogonal strengths may be missing an important point. In practical terms, stabilisation mechanisms may be unconservative in their use in design if that design method relies on an orthogonal property being mobilised and being performance-governing.

DISCUSSION 2

In making an observation that traffic orientation is important to designing with biaxial geogrids, it is normal to seek a performance-governing, or a performance-indicating property, of the geogrid.

A lead was given on such an investigation by (Kinney 1995) when he investigated and sought performance-governing geogrid features. It was indicated that the stability of the geogrid aperture was a predictive performance indicator of the trafficking data obtained by (Webster 1993). Webster also identified a range of geogrid characteristics that he considered were significant in their influence on performance. Included in the list of characteristics was the property of stiffness. This being the case, an investigation of stiffness culminated in testing the tensile strength of a sample of biaxial geogrid when loaded at orientations from MD-45º to MD+45º. The test procedure adopted was ISO 10319: 1996 as, within its scope, is the latitude to test at non-orthogonal orientations. Figure 6 shows a typical arrangement of the sample in the jaws of the Instron-type test equipment.

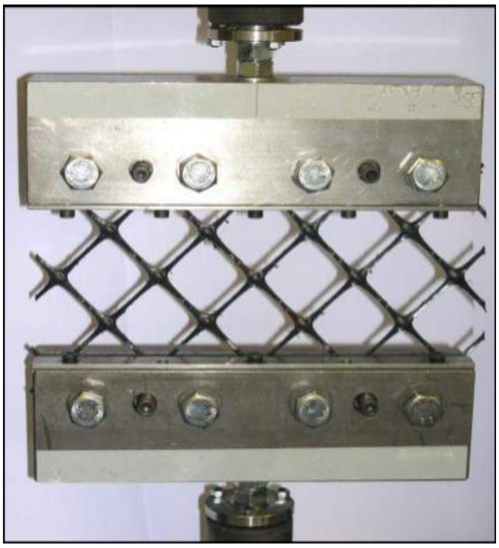

Figure 7. Sample under test

The profile of tensile stiffness, at low strain, can be plotted on a polar diagram, as shown in Figure 8.

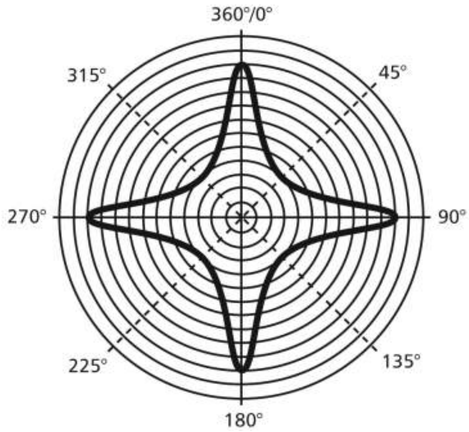

Figure 8. The polar diagram for tensile strength at low strain

A low strain level was adopted simply to relate the stiffness to a strain level that pertains to the peak strain of the pulse felt by a geogrid under a moving wheel and acting in the confinement reinforcing mechanism. It can be seen that the stiffness across the diagonals is about half the value of the stiffness in the orthogonal directions.

Combining the stiffness and the performance parameters, in a ninety-degree sector, normalised the MD, shows a close correlation, in terms of the cruciform shape in polar plots of the stiffness and performance property.

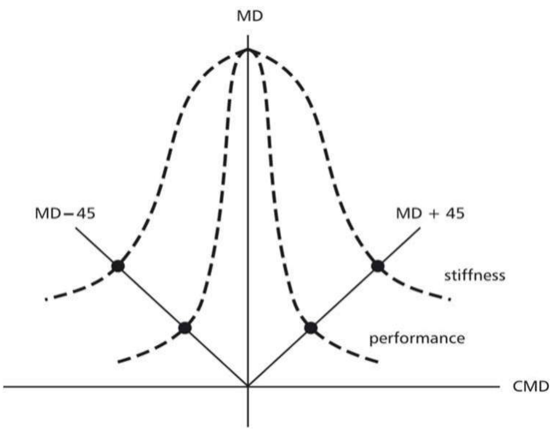

Figure 9. A combined plot of radial stiffness and associated performance

The polar plot also shows that the performance is highly sensitive to stiffness at any given orientation: the ratio of stiffness is around 2, (MD/(MD+45)), and the ratio of performance, (ditto), is around 4.

In order to use this type of information for product development purposes, the radial nature of load distribution through a mechanically stabilised layer is axiomatic. This then leads to the geogrid, for optimum effect in practical applications, needing to offer a near-constant radial restraint. Figure 10 is a diagram that shows a generic form of geogrid with its arrangement of integrally connected tensile elements. To create an optimised form of geogrid then the polar stiffness diagram needs to be enhanced beyond that of a biaxial geogrid so that, (as shown in the inset), the stiffness at low strain polar plot is transformed from a cruciform shape to a near-circular shape.

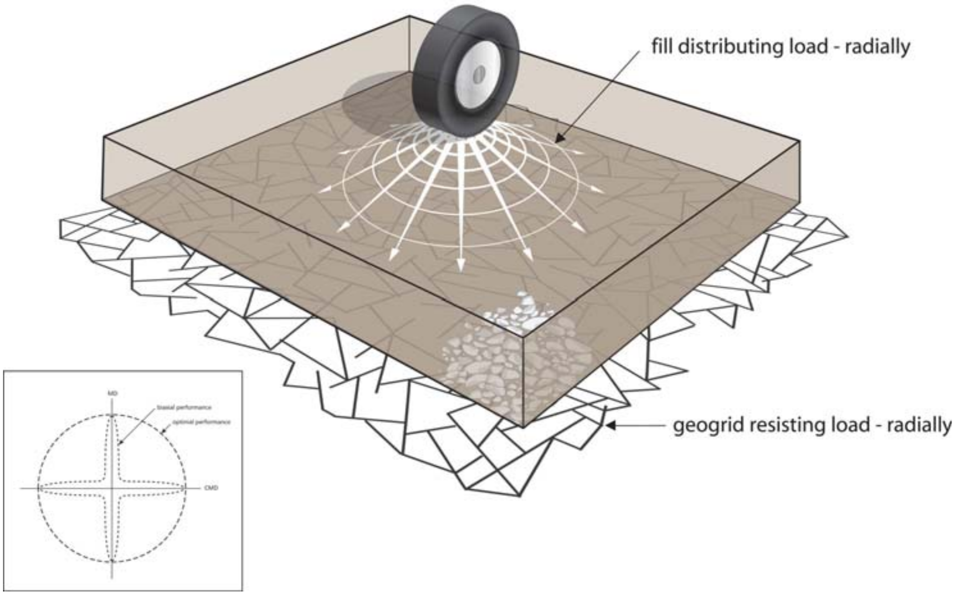

Figure 10. Radial load distribution and radial restraint, (the inset indicates the enhancement from a cruciform to a circular polar plot for optimal performance).

CONCLUSIONS

1. This short series of tests on a monolithic biaxial geogrid has indicated that the trafficking performance (the traffic improvement factor) is a highly directional phenomenon.
2. It has shown that the trafficking performance has a relationship with stiffness at low strain when both are measured radially. Accordingly, radial stiffness at low strain is a performance indicator.
3. It suggests that designs based on material properties declared in orthogonal directions are not conservative.
4. In no part of this investigation has the ultimate (quality control) tensile strength been considered as a performance-governing or performance-indicating parameter, thereby echoing guidance given some two decades ago. (Webster 1993).

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