Short Communications

SI Units in Soil Engineering

by

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Introduction

THE switchover from the British to Metric System of Units, based on Indian Weights and Measurements Act of 1956, has been indeed a great achievement. This has removed most of the mass confusion that existed in the use of units for physical measurements in scientific and engineering community in the country. At the under-graduate level of teaching, the changeover is rather complete, and most of the text books now adopt the Metric System of Units. Of course, the mental readjustment is not yet fully accomplished by many field personnel.

Soil engineering is one of those areas that have a number of different units in common usage. The laboratory people, following their counterparts in physical sciences, use some sort of metric system, usually the C.G.S. system, for simple laboratory experiments. With equal ease they apply M.K S. system in consolidation and triaxial testing, and it is not uncommon to find the use of British Engineering Units for compaction tests. The practising soils and foundation engineer is somewhat consistent (in British units), although he alternates between pounds per square inch, tons per square foot, etc. Strictly speaking, the use of force as a basic unit is not correct; it is the mass that should be the basic unit, with force derived according to the Second Law of Motion of Newton. The use of kilogram as a unit of force rather than mass is the most obvious inconsistency in M.K.S. system. This is due to our adopting metric technical units which are the counterparts of British gravitational units, in vogue at the time of switchover.

The General Conference of Weights and Measures, which is an international organisation and of which most countries including India are members, is responsible for prescribing fundamental units of weights and measures all over the World for purposes of science, technology, industry and commerce. The Eleventh General Conference which met in 1960 recommended a unified, systematically constituted and coherent system of fundamental, supplementary and derived units for international use. This system, called the International System of Units (Le Systeme International d'Unites), and designated by abbreviation, SI, is now legally compulsory in about twenty countries. Apart from its intrinsic merits, it has the great advantage that one system covers all situations—both theoretical and

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practical. SI is a modernised version of metric system. It is likely to become in time the only common, and perhaps the only legal system even in countries which at present use the British system. For example, the Board of Directors of American Society of Civil Engineers has stated in 1970 that all publications of the Society should have all measurements in both customary and SI units. All authors of Journal papers are being asked to prepare their papers in this dual-unit format. Until this practice affects the majority of publications, the Society is continuing to print a table of conversion factors. Geotechnique and Canadian Geotechnical Journal have already required that all measurements in published articles be in SI units. The Institution of Engineers (India) prefers SI units in its publications. The Weights and Measurements Committee of Indian Standards Institution has recently recommended the revision of Central Law relating to weights and measures to include International System. A refresher course has been conducted in 1969 by Indian Institute of Technology, Madras, to pave a smooth transition in switching over to SI units for teachers in engineering colleges. One of the recent text books, "Critical State Soil Mechanics" authored by A.N. Schofield and C.P. Wroth and published in 1968 in England, uses SI units. It would thus seem that the new system is already coming into effect, although, some time would be needed to realise its full impact in engineering practice.

Effective metricization did not begin in India until about 1961, whereas SI units were formulated in 1960. It is, therefore, unfortunate that we did not switch directly to SI units. Whatever may be the reasons for not taking up SI, we are now faced with a second switchover within a decade. The purpose of this paper is to bring out the salient features of the new system, with special reference to problems in soil engineering, and to recommend its immediate adoption.

SI Units

Summarising from the Guide to the use of SI units (Indian Standards Institution, 1969), the system is fully coherent and rationalised, and is based on the common metric units for length (metre), mass (kilogram), time (second), etc. There are six base units, all of which have precise definitions, names and symbols. Two supplementary units and twenty-seven derived units are incorporated. Principles for the use of prefixes for forming multiples and sub-multiples of units are also laid down. Thus Newton and Watt are the derived units of force and power respectively. Newton replaces the kilogram-force so that the name of the unit indicates that it is a unit of force and not mass. Only one unit exists for each physical quantity, and all other mechanical quantities such as velocity, work, etc., can be derived from the basic units.

A major advantage of the system is that it is fully coherent. This means that a product or quotient of any two unit quantities is a unit of the resulting quantity. For example, unit area is unit length squared, and unit force is the product of unit mass and unit acceleration. The coherent unit of velocity is metre per second (m/s) and not kilometre per hour. It may be mentioned that many of the engineering units in the present F.P.S. and C.G.S. systems are not coherent (e.g., acre, pound-force, kilogram-force).

Newton, the coherent unit of force (equalling 10^5 dynes) is an important one because it is the ingredient of many of the units which are commonly used in engineering, such as pressure or stress (N/m^2), energy

(N.m, or joule), power (N. m/s, or watt), etc. Newton is independent of earth's gravitation and hence avoids the confusion that is so much prevalent in science and technology. In fact, the definition of Newton facilitates the use of joule and watt.

The use of auxiliary units is discouraged in SI. Thus the unit of pressure is N/m^2; the atmosphere is not used. Similarly, heat is not expressed in calories, because all forms of energy are measured in joules. The advantage of identical mechanical and electrical power units is unique in the International System. Multiples and fractions of units are normally restricted to powers of 1000; e.g., mm, m, km. So the centimetre is frowned on in the strict SI. On the other hand, the step between 1 mm^3 and 1 m^3 is so large that the litre ($=10^{-3}$ m^3) is retained as a convenient unit of volume.

The common prefixes such as kilo and milli should be used to indicate orders of magnitude of the basic or derived units and to reduce redundant zeros. They should not be applied to the denominator of a combinational unit. For example, the unit of pressure is Newton per square metre and not Newton per square centimetre or Newton per square millimetre. If larger quantities are to be indicated, kilo Newtons per square metre or mega Newtons per square metre should be used as units.

Table I summarises the various units of interest in SI. There is not likely to be any difficulty in the adoption of base units of length, mass and time of the new system, since these are already in usage in M.K.S. system. It is with respect to the derived units of force, stress, pressure, unit weight, density, etc., that the SI may cause some difficulty to soil engineers, and the subsequent sections will hence concentrate on these units.

Force

SI unit of force is derived and is designated the Newton(N). It is the force which when applied to a body having a mass of one kilogram, gives it an acceleration of 1 m/s^2. Conversion factors for common engineering force and weight units are :

$$1 \text{ lb-force} = 4.448 \text{ N}$$
$$1 \text{ kg-force} = 9.807 \text{ N}$$

TABLE I
Some Units in SI System.

Unit	Name	Symbol
Force	Newton	N
Stress, pressure	Newton per square metre	N/m^2
Volume	Cubic metre	m^3
Mass density	Kilogram per cubic metre	kg/m^3
Unit weight	Newton per cubic metre	N/m^3
Work, energy	Joule	J
Power	Watt	W

For ordinary engineering practice, the Newton is rather small (of the order of 100 gm-force), equalling approximately the weight of a large apple. Measurements of such items as column and pile loads, weights of materials for an embankment, etc., would be very large indeed, and therefore, somewhat awkward. Hence, in accordance with the rules of prefixes, it is relatively easy to adjust the larger numbers to more manageable quantities, which would be more appealing. Fortunately the symbols are not too awkward and the inherent simplicity of decimalization will outweigh any initial reluctance to use them.

The usual prefixes would be kilo (10^3) and mega (10^6), so that engineering forces and weights would be converted to kilo-Newtons (KN) and mega-Newtons (MN). M is the symbol used for mega, intended to remove the confusion with the symbol for metre. Thus a load of one tonne would approximate ten kilo-Newtons. It then becomes a matter of simply getting accustomed to hearing and saying things like "pile load of 100 KN."

Stress and Pressure

The derived unit for stress and pressure is Newton per square metre. Some useful conversion factors are :

$$1 \text{ kg-force/cm}^2 = 9.807 \times 10^4 \text{ N/m}^2$$
$$1 \text{ lb-force/in.}^2 = 6.895 \times 10^3 \text{ N/m}^2$$
$$1 \text{ ton-force/ft}^2 = 95.76 \times 10^3 \text{ N/m}^2$$
$$1 \text{ atmosphere} = 1.013 \times 10^5 \text{ N/m}^2$$

A square metre is nearly the area of a domestic dining table, and with a Newton being of the order of 0.225 lb force, the unit of stress in SI is quite small. One mm of water pressure is about 9.807 N/m^2. This is rather inconvenient and it is a fact of the new system that must be accepted. However, as in the case of units of force, large numbers can be managed by use of prefixes. Thus, 1 lb/in.^{2} might be more conveniently expressed as 6.895 KN/m^2. For ordinary triaxial testing of soils, cell pressures do not normally exceed 200 to 300 psi, or 1379 to 2068 KN/m^2. We may find it more meaningful to express these as 1.4 to 2.1 MN/m^2. In time, after sufficient acquaintance with the system, a rounded interval would come into use; for example, 1.5 MN/m^2 and 2.0 MN/m^2. In soil engineering, there already exists the approximation, 1 kg force/cm^2 = 1 ton force/ft^2 = 1 atmosphere, which is nearly 100 KN/m^2, the error ranging between 2 to 4 percent. While expressing foundation stresses, earth pressures, allowable bearing values, etc., the unit of MN/m^2 would be commonly used. In the laboratory, loads would be normally measured in N or KN, and areas in mm^2; computation of unit stresses would be simple.

A numerical problem in mechanics should create the necessary familiarity with the International System : a simply supported span of 12 m with a loading of 5 KN/m would have a maximum bending moment of 90 KN/m at the centre of span. If one chooses a rolled steel joist, ISHB 250, the depth of the beam being 250 mm, and the moment of inertia equalling 7.984×10^7 mm^4, the maximum fibre stress in the cross-section of the joist would work out as 14.1×10^7 N/m^2, according to the well-known formula ($f = My/I$).

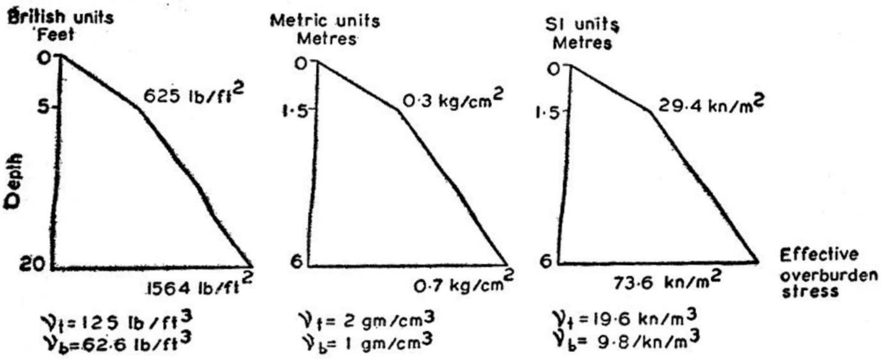

FIGURE 1 : Computation of effective overburden stress in various systems of units.

It should be mentioned that the unit of bar, equalling 10^5 N/m^2, would be allowed in conjunction with SI units, although it is not a preferred multiple. In addition, it is expected that hectobar, which is equal to 10^7 N/m^2 will be used as it approximates 1 kg-force/mm^2. One ton-force/in.^{2} is about 1.5 hectobars. In the above problem the stress may be expressed as 14.1 hectobars.

Density and Unit Weight

In general, mass density, or mass per unit volume is not of interest in soil mechanics. Density is commonly used for unit weight, as in the case of density of embankments, etc. Unit weight, or the weight per unit volume, is the engineering measurement, and is expressed as Newtons/cubic metre. Some conversion factors are :

1 gm-force/cm^3 = 9.807 KN/m^3
1 lb-force/ft^3 = 0.157 KN/m^3

While it is agreed that 1 gm-force/cm^3, the unit weight of water, is convenient for computations, the use of the value in KN/m^3 will prove no more complicated than the use of 62.4 lb-force/ft^3, which is prevalent in F.P.S. system of units. Unit weight of concrete is 23.6 KN/m^3, which, with familiarity, would be an easy number to remember. Typical unit weights in soil mechanics might be 12.6, 15.7 and 19.6 KN/m^3, corresponding to 80, 100 and 125 lb/ft^3 respectively.

The example illustrated in Figure 1 is offered to obtain a feel for numerical values in SI. This is a typical problem in the computation of effective overburden stresses. The water-table is at a depth of 1.5 m (5 ft) from the ground level and the saturated unit weight of the soil is 19.6 KN/m^3 (125 lb/ft^3). The submerged unit weight is 9.8 KN/m^3 (62.6 lb/ft^3). Assuming the entire soil to be saturated, the effective stresses at depths of 1.5 and 6 m are shown in the figure, according to various systems of units.

Summary

This paper has outlined the salient features of SI, which is a modernised form of metric system. Some physical quantities of interest in the field of soil engineering have been presented as they occur in the new system. While concluding that the switchover from the present metric system to SI is comparatively easy, it is suggested that the changeover should be taken up immediately.

Acknowledgement

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Reference

INDIAN STANDARDS INSTITUTION (1969) : "*Guide to the use of International System (SI) of Units.*" S.P. 5-1969, Manak Bhavan, New Delhi.