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VIERGEVER M.A. and de FEIJTER J.W.
Delft Soil Mechanics Laboratory, NL
MOUW K.A.G.
Rijkswaterstaat, Deltadienst, The Hague, NL

Bi-axial tensile strength and resistance to cone penetration of membranes
Résistance des membranes à la traction biaxiale et à la pénétration au cône

RÉSUME

Pour la construction d'un seuil à utiliser lors de la fermeture de l'estuaire de l'Escaut de l'Est on a besoin d'une membrane, qui grande résistance à la tension, qui résiste des pierres qui tombent, et qui reste imperméable à toutes conditions. On a donné l'occasion à remplir ces exigeances à quelques fournisseurs. Un nombre d'essais a été executé pour diriger et corriger le développement de membranes nouvelles, et pour enfin en faire un choix. La série d'essais consiste en trois parties, dont deux sont à mentionner ici:

- Un appareil à éprouver la résistance à la tension bi-axiale a été utilisé pour déterminer la relation tension-déformation à une augmentation constante de la déformation, ainsi que la résistance ultérieure d'échantillons en forme d'une croix.
- L'essai second mesure la déformation et la résistance à la pénétration par cône; cet essai est une schématisation des pierres qui tombent sur la membrane qui couvre le seuil dans l'Escaut de l'Est.

Cet article décrit la disposition des expériments, et en donne quelques résultats.

INTRODUCTION

Within the framework of the execution of the Delta-Works, a storm-surge barrier is being constructed in the Oosterschelde - an approximately 9 km wide estuary with channels to a maximum depth of 35 m in the southwestern delta of the Netherlands.

The storm-surge barrier will be based on caissons on which piers will be installed. Between these piers movable sluice gates will be suspended which can be closed during storms. In closed condition, the sluice gates rest on a pervious sill. The sill on the sandy bottom is conceived to be built up of a sand-resistant layer, followed by stone layers of different dimensions and gradations, covered with a layer of concrete blocks of 7.5 tons each, in which the bottom support for the sluice gate is accomodated (see Fig. 1).

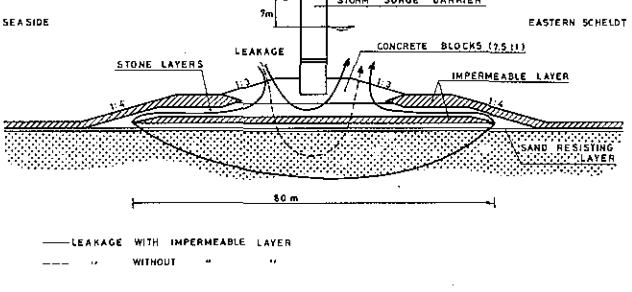

Fig. 1: Cross-section of storm-surge barrier with leakage pattern

Impervious layers on the slopes of the sill and in the stone layers have been extended to increase the length of seepage in the sandy soil. At a greater length of seepage the gradients are less steep, resulting in a reduced chance of sand being washed out of the soil. As far as the impervious layer between the stone layers is concerned, a plastic membrane is being considered. In this article attention is paid to practical requirements and test methods for these membranes.

REQUIREMENTS

The above-mentioned layer must retain its impermeability under all expected conditions. This implies requirements not only for impermeability - not dealt with in this article - but also requirements for mechanical strength, durability and dimensions of the membrane. The strength requirements are mainly determined by the location of the membrane in the sill and the mode of installation of both membrane and sill.

During sinking, the membrane is unrolled and tensioned between two anchored pontoons, during which a force of approximately 60 kN/m' is exerted in one direction. If the force is increased by currents or other influences, slippage will occur in the tensioning device. Furthermore, in case of spanning a hole of approximately 0.50 x 0.50 m^2 in the underlying stone layer, the membrane should be capable of taking and trasferring the overlying concentrated load to the edges of the plane.

This force has been put at 200 - 250 kN/m', depending on the stress-strain behaviour of the membrane. At a higher deflection of the membrane, the component in the plane of the membrane remains smaller (Fig. 2).

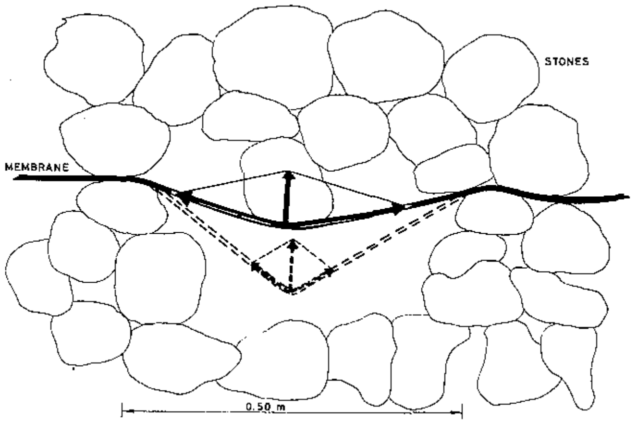

Fig. 2: Static loading of membrane

A stone layer, consisting of stones with a maximum dimension of 0.40 m (approximately 100 kg) is put on top of the membrane. The stones are dumped from the waterline and reach the membrane at equilibrium velocity (approximately 4.5 m/s). The membrane lies on the bottom under tension (60 kN/m') and spans the roughnesses mentioned previously. It should be capable of catching the falling stones without losing its impermeability. A falling stone has a maximum energy of approximately 1000 joules.
Also in the longer term the membrane should be resistant to the agressive influences of the surrounding seawater; these requirements are left out of consideration in this article. The dimensions of the membrane have been put at approximately 40 x 80 m^2.
Summarizing, the requirements that are being considered in more detail are:

- the strength in two mutually perpendicular directions in the plane of the membrane at identical strain in these directions: 200 kN/m' at 15% strain at ultimate stress or 250 kN/m' at 10% strain at ultimate stress;
- an energy absorption of 1000 joule on loading perpendicular to the plane of the membrane in the case of a span of 0.50 m.

ORIGIN AND SET-UP OF INVESTIGATION

None of the existing membranes could meet the requirements. Hence, it was necessary to develop a new membrane or to assemble one from existing components.
To this end, a number of suppliers and manufacturers were invited to submit proposals. They were free to meet the requirements according to their own ideas.
At the same time a programme was set up for testing the various membranes, for guidance, where necessary, in the development and finally to come to a good comparison of these membranes. For this purpose, a number of test methods have been developed.
In this article attention is paid to the determination of biaxial tensile strength and strain.
Furthermore, the determination of the energy that can be absorbed by the membrane is discussed. This energy is determined in the cone-penetration test.

TESTING ARRANGEMENT FOR DETERMINATION OF BIAXIAL TENSILE STRENGTH

The tests have been carried out in a test set-up at the Research Group, Plastics and Other Building Materials of Civil Engineering Department of the Delft University of Technology (see Figs. 3 and 4).

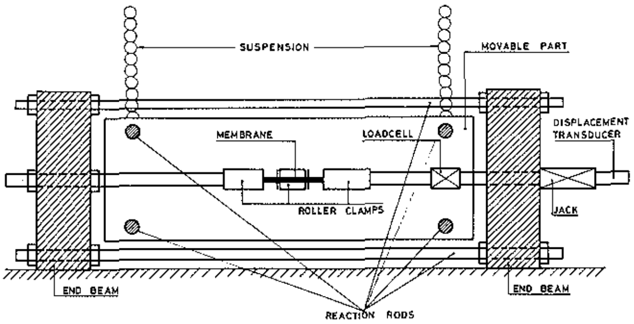

Fig. 3: Principle of biaxial tester

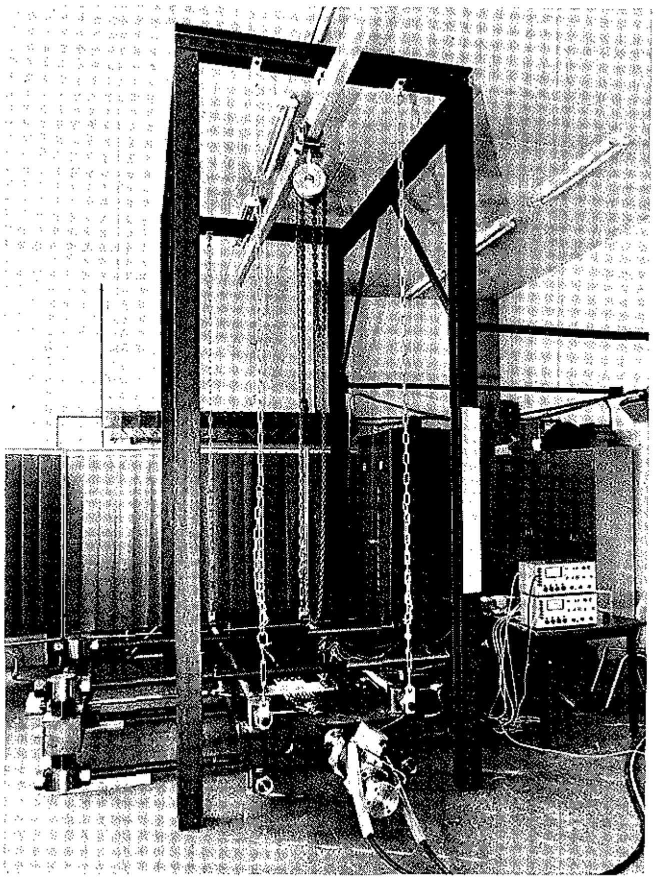

Fig. 4: Biaxial tester

The set-up comprises two horizontal, mutually perpendicular grips. Each grip consists of two end beams held apart by four reaction rods. The specimen is anchored to the end beam on one side. A jack, which transfers the required tensile strength and displacement to the specimen, is attached to the opposite endbeam. As only one side of the specimen is pulled, the centre of the specimen deviates from the centre of the grip. In the case of a fixed set-up of the two grips, this would result in the specimen no longer being loaded in two mutually perpendicular directions.

Hence, one of the two grips is suspended from long chains to make displacements in the horizontal plane possible (see Fig. 5).

Between specimen and jack, a load cell and a displacement transducer are mounted in both directions of pulling. The jacks can be both force- and displacement-controlled at different rates (from 5.10^{-6} to 5.10^{-2} m/s) up to a maximum force of 150 kN and a displacement of 0.10 m.

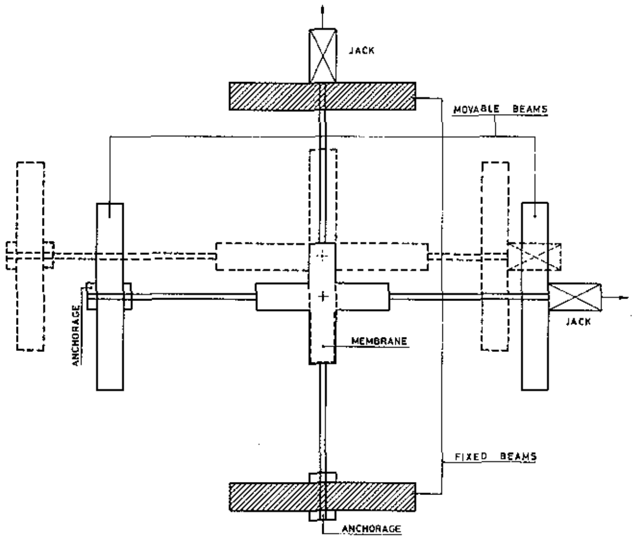

Fig. 5: Shift of the movable beams in the horizontal plane (due to strain)

CLAMPING AND SHAPE OF SPECIMEN

Care must be taken that the test result is not affected by clamping and that the clamps can transfer the maximum tensile force of the specimen to the anchorages or the jacks. It was decided to opt for a roller clamp where the specimen is self-clamping (see Fig. 6).

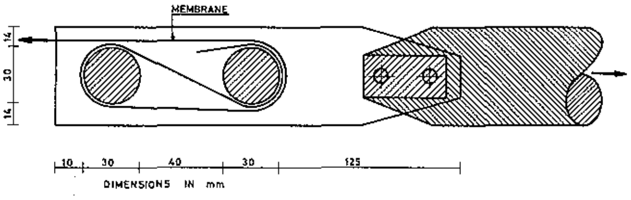

Fig. 6: View of test specimen in roller clamps

To prevent the clamps from affecting the test result, a sufficiently long starting length is required. As a consequence, a cross-shaped specimen with four projecting strips is used (see Fig. 7).

The strips have a width of 0.15 m and a length of 0.60 m, of which approximately 0.40 m is used for clamping. The inside plane of the cross is then loaded biaxially and measures 0.15 x 0.15 m^2. The corners between the strips have been curved with a circular arc with a radius of 20 mm to prevent tear-in at the corners.

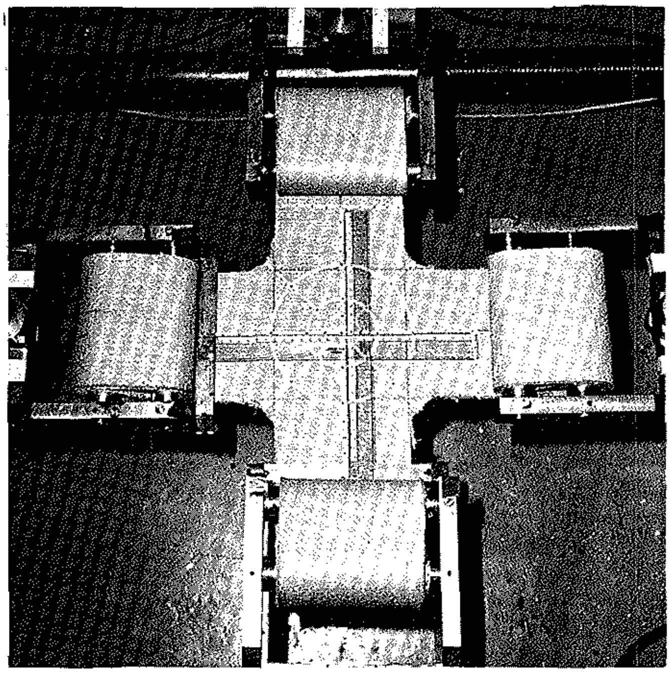

Fig. 7: View of test specimen in roller clamps

MEASUREMENT

All measurements have been taken with displacement-controlled jacks, because this offers the closest similarity to actual conditions.

The two jacking forces (yy) versus diaplacement (x) of the jacks have been recorded by an xyy recorder. As the displacement of the jacks includes the extensions of the specimen strips the deformations of the specimen have also been observed separately. To this end, a pattern of concentric circles and radial lines have been drawn on the inside plane of the specimen.

During each test approximately 10 photographs are taken of the drawn-on pattern. The deformation of the specimen is then determined with the aid of two mutually perpendicular rulers located over the specimen (see Fig. 7). These photographs also show the readings of the load cell and time.

From these stress-strain relations,tensile strength and strain at ultimate stress are determined.

TESTING

First the specimen is clamped in the roller clamps under a amximum tension of 4 kN/m'. Subsequently, the specimen is pretensioned stepwise on the anchored sides in two directions to a tension of 40 kN/m'. Pretension is done to stretch the specimen tightly between the clamps and have them operational. The displacement of the clamps during pretensioning also gives an impression of the structural strain in the specimen.

Finally, the specimen is loaded to failure at a rate of 5 mm/sec by means of jacks, during which the measurements described above are carried out.

REMARKS ON RESULTS

As the investigation has not yet been completed, we can only mention some trends in the results.

The first trials were carried out at a rate of ap-

proximately 0.06 mm/sec. It was found that flow of the adhesives occurred in the clamp in the case of membrane constructions built up of various layers cemented together with visco-elastic adhesives. As a result, the various parts of the membrane slid upon one another. It was then decided to perform all tests at a rate of 5 mm/sec, during which this failure did not occur. From other specimens it was established that at these rates the tensile strength and strain were hardly affected by deformation speed.
To study the effect of biaxial loading, a number of specimens have been tested both mono- and biaxially. A relatively slight decrease in tensile strength (of the order of 10%) was observed in the case of biaxial loading. With fabrics, this is due to the fact that, on biaxial loading, the threads subjected to pulling are pulled less flat than in the case of monoaxial pulling.
Strain. on the other hand, decreased considerably owing to the prevented neck-in (of the order of 20 - 50%). Figure 8 shows a mono-axially (below) and a bi-axially loaded specimen (above).

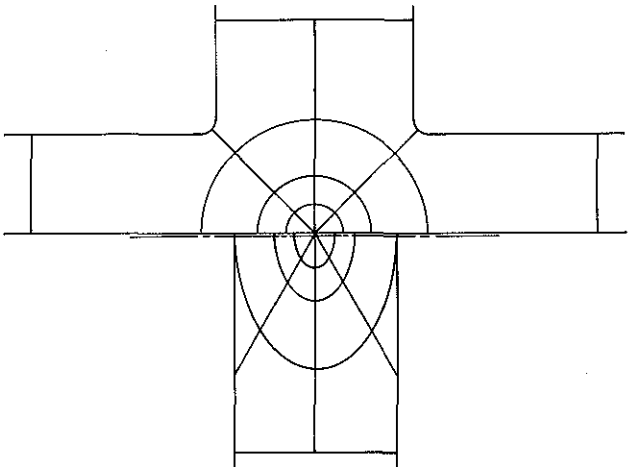

Fig. 8: One- and two-dimensionally loaded specimens at the same loading

In the case of membrane constructions with thick plastic films, the strain on biaxial loading was found to have disappeared almost completely, contrary to monoaxial loading, where strains of more than 100% were observed.

Furthermore, it is clear that the breaking strength of a membrane construction is not equal to the sum of the tensile strengths of the components; at best, the strengths of the various parts may be summed at equal strain.
In a membrane with identical properties in two mutually perpendicular directions, fracture occurs in the inside plane of the cross because here the biaxial tensile strength is lower than the monoaxial tensile strength in the strips. If the properties are not equal in both directions, fracture occurs in the strip where breaking strength is reached first. As a consequence of the stress concentration at the transition of the inside plane to the strip, fracture mostly occurs there.

CONE-PENETRATION TEST

The energy absorption of the membrane is determined in the cone-penetration test until leakage occurs as a result of cone penetration. Here the cone is a representation of a falling stone.
To this end, the membrane is mounted on a drum and clamped at the edge. The whole is subsequently placed under the cone, which exerts a load on the membrane at a constant increase in force of 50 kN/sec up to a maximum of 20 kN. Force and displacement as a function of time are then recorded (see Figs. 9, 10 and 11).

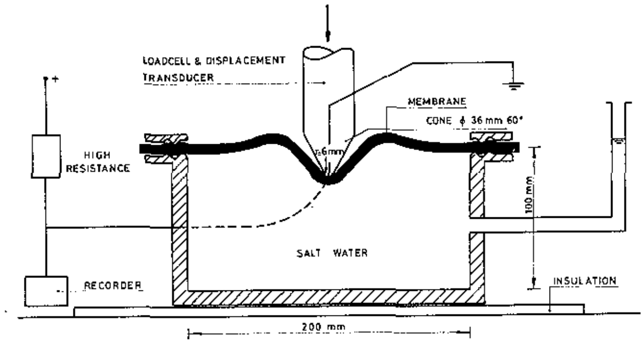

Fig. 9: Principle of cone-penetration test

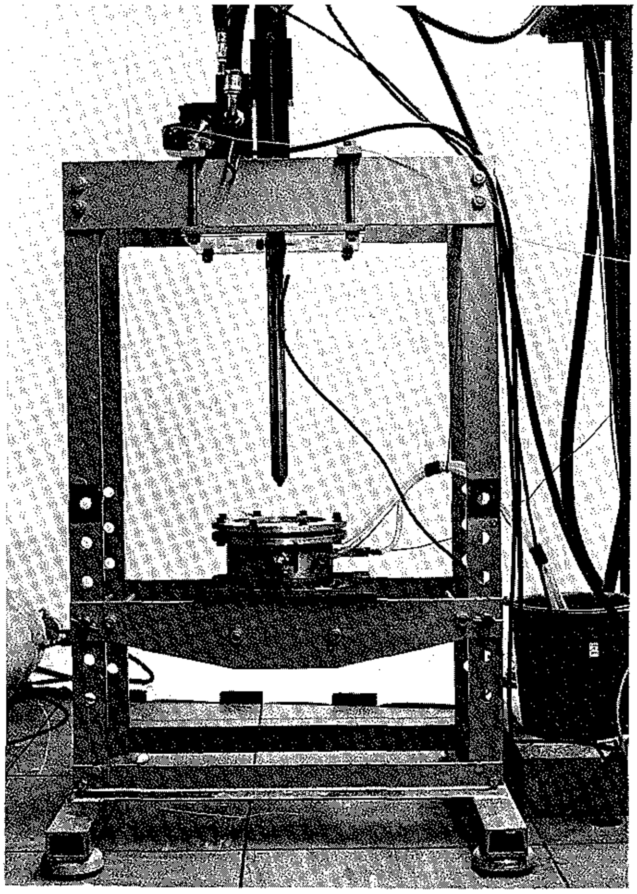

Fig. 10: Set-up of cone penetration test

The drum is filled with water and is in open communication with the atmosphere via an overflow.
As a result, pressure built-up in the drum is limited. The water in the drum with the limited flow-

away facility is meant as a simulation of actual conditions where the water can flow away into the underlying stone package.

To indicate when leakage occurs, a leakage indication has been provided (see Fig. 9). The underlying principle is that in case of leakage the circuit between recorder and earth is closed by means of the water made conductive with salt and the cone connected to earth.

As the drum has a diameter of not more than 0.20 m, the energy that the membrane should be capable of taking is not 1000 joule, but only $(\frac{0.20}{0.50})^2 \times 1000 =$ 160 joule.

Besides the test in which the membrane is placed on the drum without tension, tests have also been carried out in which the membrane is first pretensioned at 60 kN/m' in the longitudinal direction, during which deformation in the other direction is prevented. The 60 kN/m' is based on the forces acting during sinking of the membrane.

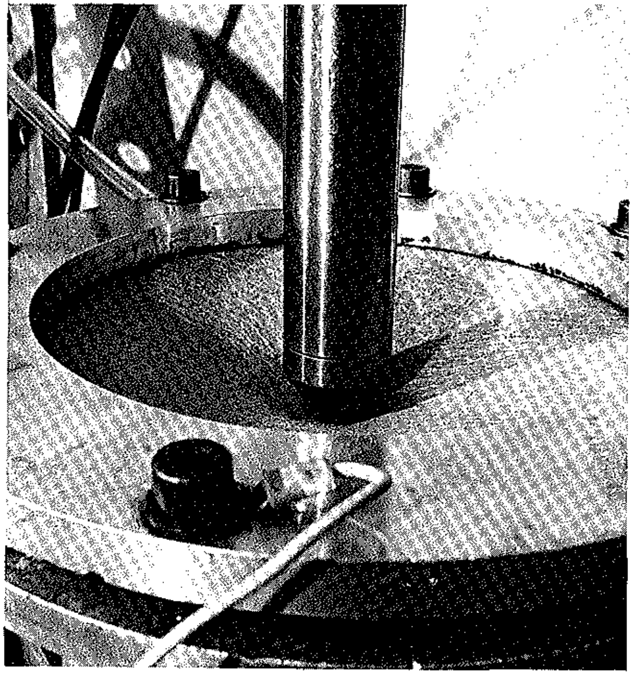

Fig. 11: Detail of cone penetration test

REMARKS ON RESULTS

As a result of pretensioning of the specimen in the longitudinal direction, deformations decrease at approximately the same tensile ultimate strengths so that energy absorption also decreases.

With membranes into which fabrics have been incorporated, the fabric threads are in the first instance pushed from each other by the cone; this is dependent on thread mobility.

With membranes with an impervious filter over the fabric, the filter is clamped between cone and the fabric threads that have been pushed sideways. In case of continuous displacement of the cone, the film must locally yield very high strains, as a result of which fracture occurs.

If, on the other hand, the fabric is located over the film, then fracture of the film occurs at the moment that a sudden strong load increase must be taken as a result of fracture of the protective layer.

If the membrane is made up of layers perpendicular to each other that can mainly take a force in one direction, then fracture will result in the weak direction of the two separate layers. In this case the layers do not therefore act as one unit; the force resulting in cleavage in the weaker direction is therefore decisive.

RETROSPECT

In this article two tests have been described which are intended to establish a number of properties of plastic membranes.

The tests are promarily intended for purposes of comparison and have been attuned as far as possible to the practical situation to be expected. The advantage of these laboratory tests is that a large number of data on plastic membranes tested under identical conditions are obtained over a relatively short period at relatively low cost and lottle effort. Hence, it is possible to feed back in good time during the development of the membranes.

For comparison of a number of selected plastic membranes under practical conditions, a full-scale test is planned.

REFERENCES

REINHARDT, Hans, W.: "On the biaxial testing and strength of coated fabrics", Experimental Mechanics, February 1976, pp. 71-74.