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A Strain-Gauge Technique for Measuring Deformations in Geotextiles

Une technique à jauge d'allongement pour mesurer des déformations des membranes

A method has been developed to determine strains and stresses in membranes under field conditions. Specific problems had to be overcome in relation to the high strains to be expected (in the range of ca. 10-20 percent). Some of the aspects involved are the choice of a suitable adhesive for glueing the strain-gauges to non-woven as well as to woven geotextiles, the connection of the measuring cable with the strain-gauge and the interpretation of the signal measured. As the response of the strain-gauge mainly depends on the stiffness ratio between the membrane and the strain-gauge, this value has to be determined experimentally for each type of membrane. The behaviour of the geotextile often depends on its loading.
Strain-gauge reading in practice have been simulated in the laboratory in order to determine the response of the strain-gauges as well as the stress-strain relationship of the geotextile material. As a whole, the measuring system has proved to be very reliable under practical circumstances, even when heavy loads or large deformations are applied.

Une méthode a été développée pour déterminer des déformations en membranes en situ..Des problèmes spécifiques devaient être surmontés à cause des déformations élevées (10-20 pourcents). Quelques aspects a examiner sont le choix d'une colle convenable pour attacher les jauges d'allongement aux membranes tissées ou non tissées, la connection du cable à mesure à la jauge d'allongement et l'interpretation du signal électrique mesuré. La réponse électrique de la jauge d'allongement dépend principalement du rapport de la rigidité de la membrane et celle de la jauge d'allongement; cette valeur doit être déterminée expérimentalement pour chaque genre de membrane. Le comportement de la membrane dépend de la séquence des déformations subie dans le temps. La séquence selon le mesurage à jauge d'allongement en pratique a été simulée au laboratoire afin de déterminer la réponse des jauges autant que le rapport contrainte/déformation des membranes. En conclusion: le système à mesure a montré sa sûreté en pratique. même si les charges ou les déformations sont elevées.

INTRODUCTION

Very soon after the start of the working group G2 of SCW (the Netherlands Road Construction Research Centre based at Arnhem, Holland) at the end of 1976, investigating the feasibility of the application of geotextiles in road construction, it turned out that the main problem in studying this subject, would be the selection of a measuring device to be used in field experiments for monitoring strains. An inventory was made of measuring methods already in use, but most of them did not seem to suit our purpose. It was concluded, however, that the application of strain-gauges could be considered as useful. Enka-Research (Arnhem-Holland) had some experience with a measuring method, using a high performance strain-gauge (strain capacity up to 20%), type EP-08-40, CBY-120, supplied by Micro-Measurements.
A number of model experiments had been performed, and it turned out that this particular type of strain-gauges was suitable for usage in combination with coated fabrics. Unfortunately, glueing of the strain-gauges to geotextiles was found to be a problem.
Experiments, carried out in the Materials Science Laboratory at the Department of Civil Engineering in Delft, showed that a certain type of silicone adhesive could be applied (Terostat-33, manufactured by Teroson GmbH, Heidelberg, W. Germany).
This type of cement offers an extra advantage because it is waterproof.
The behaviour of the Terostat is purely elastic and vertical loads do not effect the results of the measurements.
Summarizing, the use of an appropriate strain-gauge technique has the following advantages over other methods:

- registration of strains up to more then 10 percent is possible
- there is little effect on the behaviour of the geotextile
- reading-out at great distance is possible
- it is independent of vertical pressures
- reliability for long periods of service life
- the handling is easy

Firstly, the method of glueing strain-gauges to geotextiles is described, followed by a report on the feasibility tests.
Because of the very high possible strains, the Wheatstone-bridge, used to measure the strains, is no longer linear. The increase of electrical resistance of the strain-gauge, usually negligible if strains are small, has now to be taken into account; the formulae for this case will be derived.
A simple laboratory test, verifying the sensitivity of the strain-gauge glued to different types of geotextiles will be discussed.
Finally some results of field tests will be presented.

APPLICATION METHOD

The application takes three steps.
The first one is the glueing of the strain-gauge to the geotextile; the second is the cable connection between strain-gauge and measuring cable; the final one is the protection of the strain-gauge, including the connections, against external influences, especially against water.

The silicone glue is highly elastic, and it follows the elongation of the geotextile very well, without exerting any force on it. On the other hand, a small force is needed to extend the strain-gauge. This force has to be transferred across the adhesive layer, causing deformations due to shear stresses. In order to keep these deformations as small as possible it is necessary to apply but a very thin layer. The smaller the deformation the better is the response of the gauge. When the modulus of elasticity of the geotextile material is very low, the force needed to strain the gauge strip will locally influence the behaviour of the geotextile.
This also means an indesirably decrease of its response.

In conclusion: optimum results are produced with an adhesive layer of minumum thickness in combination with a high modulus geotextile.
In order to minimize the scatter of the results for different installation method, the method should be standardised and moreover the operation should preferably be carried out by one and the same individual.
In our laboratory the following procedure is adhered to.
Firstly apply a thin layer of the silicone glue to the geotextile. Next scrape off as much as possible. After having pressed a strain-gauge into the glue and having covered it by a thin teflon strip, the assembly is compacted by a dead weight for appr. 15 minutes. After this operation final curing of the glue takes 24 hours.
After curing, a connection is made between the gauge and a terminal by means of thin wires. The terminal is glued to the geotextile in the same way as the gauge. In order to get a flexible connection the connecting wires are curled into loops (see fig. 1).

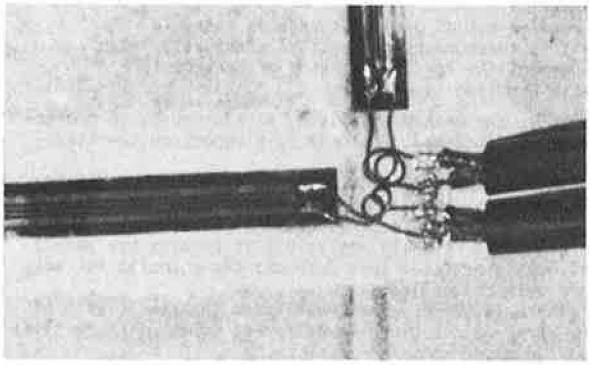

Fig. 1. Strain-gauges with connection cables.
The actual gauge length is 10 cm.

Then to the other side of the terminal, wires with a length of appr. 10 cm are fixed. This complete assembly is then covered with silicone glue to prevent damage from its future environment.
It has to be stressed, however, that the silicone adhesive should be handled under perfectly dry conditions.

The handling in the field only consists of mechanically connecting the open ends between gauge wires and the cable to the measuring device.
A shrink lining is used to protect the connections from water.

FEASIBILITY TESTS

In order to test the effects of the hardening of the silicone glue, a number of strain-gauges were glued to a geotextile (stabilenka 200) and tested after different periods of time. As mentioned before, it should be borne in mind that due to the shear deformation of the glue and due to the interaction between geotextile and gauge the measured strain deviates from the deformation the geotextile is suffering. The rate of hardening of the adhesive is of importance with respect to these shear effects.
Table 1 gives the results of the tests performed. It can be concluded that the curing of the glue is complete within five days.

Table 1. Relation between strain-gauge value and actual strain of the geotextile, in dependency of the hardening time of the glue.

strain of geo-textile	strain shown by strain-gauge, %							mean value	standard devia-tion
	age of glue						days		
%.	13	12	11	10	9	6	5		
1		0.8	0.6	0.6	0.7	0.6	0.4	0.6	0.13
2	1.3	1.7	1.3	1.5	1.3	1.4	1.5	1.4	0.15
3	1.9	2.3	2.1	2.2	2.0	2.0	2.4	2.1	0.18
4	2.9	3.1	3.2	3.0	2.8	2.9	3.3	3.0	0.18
5	3.6	4.0	3.7	3.8	3.8	3.8	4.0	3.8	0.15
6	4.6	4.9	4.7	4.6	4.6	4.6	5.0	4.7	0.17

In order to investigate whether there is any influence of creep phenomena of the glue, a strip of a geotextile, instrumented as described was stretched to about 5%. After three months the strain-gauge reading had not changed.
In order to test the sensitivity for temperature changes, a test specimen was kept in an oven at about 100^{o}C, and in a refrigerator at about -20^{o}C. At the same time, the dummy strain-gauge was kept at a temperature of about 20^{o}C. During these tests no temperature influence was found.
To test the sensibility for vertical load, a strain-gauge has been loaded with 20 N/cm^2. The measured strain results were not affected.
We can conclude from all the performed tests, that the chosen method suits our purpose.
The outdoor performance had to be tested under field conditions. The method has now been improved up to a final state that allows of reliable strain measuring in practice.

THE WHEATSTONE-BRIDGE MEASURING HIGH STRAINS

The principle of strain measurement by means of a strain-gauge is well-known. The phenomenon can be described as follows. A relative change of strain of the strain-gauge material results in a relative change of electrical resistance. The ratio k, between deformation and change of resistance characterizes the gauge, namely:

$$\frac{\Delta R}{R} = k.\frac{\Delta l}{l}$$

$$\varepsilon = \frac{\Delta l}{l}$$

$$\frac{\Delta R}{R} = k.\varepsilon \qquad (1)$$

where R = electrical resistance
ΔR = change of resistance
ε_s = relative strain

To accurately measure the resistance changes in the gauge that are usually very small indeed, a Wheatstone bridge is applied.
Even a minimum change of resistance produces a reasonably measurable change of electrical voltage between the points C en D (see fig. 2).

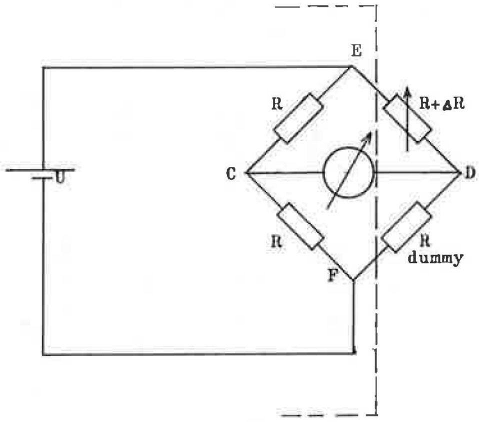

Fig. 2. Wheatstone bridge.

In fig. 2 the measuring device (Wheatstone bridge) is schematically depicted at the left of the depicted line. The dummy gauge is of exactly the same kind as the measuring one itself. It has been handled in exactly the same way and it is kept under the same environmental conditions of temperature and moisture.
At the start of the measurement, when the stain of the gauge equals zero, the measuring bridge is in equilibrium. That means that $U_c = U_d = \frac{1}{2}U$ and $U_{cd} = o$.
When strained to ε, R changes by ΔR
Then $R_{ED} = R + \Delta R$, $R_{DF} = R$

$$U_D = \frac{R_{ED}}{R_{ED}+R_{DF}} \cdot U \text{ and } U_c = \tfrac{1}{2}U$$

so,

$$U_{cd} = \left(\frac{R + \Delta R}{2R + \Delta R} - \tfrac{1}{2}\right) . U$$

Substituting eq. 1 results in

$$U_{cd} = \left(\frac{1 + k.\varepsilon}{2 + k.\varepsilon} - \tfrac{1}{2}\right) . U = \frac{k.\varepsilon}{4 + 2k\varepsilon} \cdot U$$

$$(2)\quad \boxed{\varepsilon = \frac{4\,U_{cd}}{k(U - 2U_{cd})}}$$

This means that in the case of very high strain the relationship between U_{cd} and ε_s is not linear anymore. Generally, however, if U_{cd} is negligible compared to U, eq. 2 transforms into:

$$(3)\quad \varepsilon = \frac{4\,U_{cd}}{k.U}$$

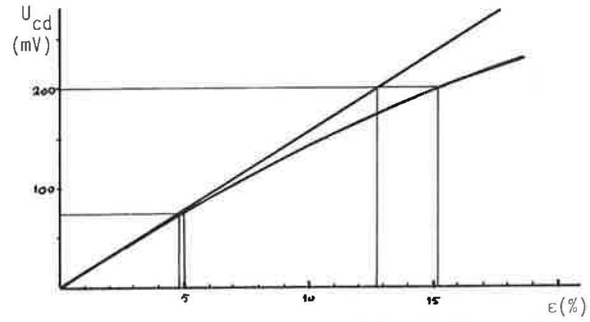

Fig. 3. Non-lineair relationship between U_{cd} and ε for high strains.

The appromixation resulting in eq. 3 is only valid for strains less than ca. 5%. In the case of higher strains, eq. 2 has to be used to accurately calculate strain from measured voltage differences.

LABORATORY TESTS ON GEOTEXTILES

Because of the dependency of the strain-gauge response on the type of geotextile as well as on the bonding method of the strain-gauge to the geotextile, it is necessary to perform a gauging test for each type of geotextile.

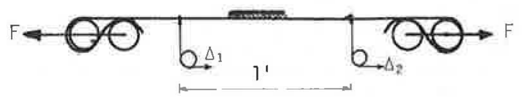

Fig. 4. Schematic set-up of a gauge test

During loading of the specimen, the strain is measured in two different ways.
The real strain of the geotextile is determined by means of two displacement transducers, placed at a distance l'. The difference between the displacements Δ_1 and Δ_2, divided by the distance l' give the real strain ε_i.

$$\varepsilon_i = \frac{\Delta_1 - \Delta_2}{l'}$$

This real strain value is compared with the strain determined by the strain-gauge, according to equation 2. Simultaneously the force F is being recorded.
Simultaneous determination of ε_i, ε_s and F produces the the stress-strain relationship, as well as the relation between ε_i and ε_s. The ratio $\varepsilon_s/\varepsilon_i$ yields the gauge response.
An example of the results of a test as described above for a strain-gauge bonded to a woven polyester fabric (stabilenka 2oo) is given in fig. 5.

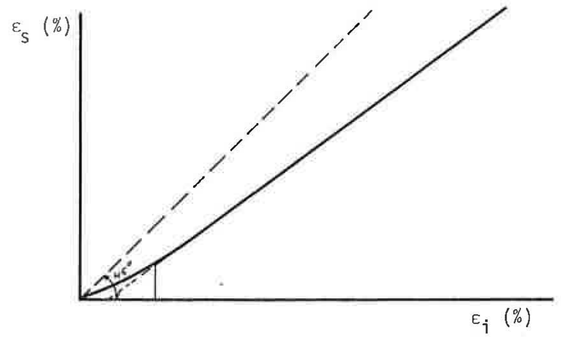

Fig. 5. Relationship between geotextile strain ε_i and strain-gauge value ε_s.

In this particular case the relation was found to be: $\varepsilon_i = 0.32 + 1.17\ \varepsilon_s$.
The correlation coefficient between the experimental results and the calculated linear approximation is 0.9995. That means that the linearized measuring method produces satisfactory results.
Moreover, the response in this case amounts to more than 80%, what in our opinion is a very good result.
As to non-wovens, the results are less satisfactory, due to their low Young's modulus, as well as to their time dependent behaviour. Because of the non-elastic behaviour it is obvious for example that the relation between applied geotextile strain and measured strain is dependent on the strain rate. For a slow, continually rising strain, the ε_i - ε_s relation for a non-woven polyester (e.g. Colbond) is found to be: $\varepsilon_i = 1.38 + 1.26\ \varepsilon_s$.
So for this material a strain-gauge response of appr. 70-75 percent has been achieved.
These are only a few examples. It is obvious that the results of the strain-gauge are very satisfactory in combination with a polyester membrane.
Whether the adhesive, i.e. the silicone type used, is also suitable for bonding of gauges to other materials, such as polypropylene and polyamide, has not been investigated up to now.
It has to be emphasized, that the ε_i - ε_s relationship gaven are only examples. The exact relationship has to be determined for each combination apart.

STRAIN-GAUGE TECHNIQUE IN FIELD EXPERIMENTS

Two types of field experiments have been conducted. The first one is the application of a woven geotextile between an embankment and a soft subsoil.
In Cuxhaven, West-Germany in 1978 40 gauges have been applied. Deformations in the fabric were very low but nevertheless it could be concluded that the developed strain-gauge technique was reliable under these field conditions. Even after a year 37 gauges were still in a good shape.
In Almere, The Netherlands in 1979 a similar field experiment was performed.
In this case the imposed deformation of the geotextile was so large that tearing occured at a strain value of about 10 percent. The registered maximum strain value however was approximately 8 percent, due to premature failure of the connections between measuring cable and strain-gauge.
In Cuxhaven as well as in Almere strain registration took place by means of a 40-channel scanning measuring bridge. The scanning method was adequate because of the very slow developments of deformation during the construction of the embankment.
An improved connecting method, by means of the earlier mentioned curled wires between the strain-gauge and a terminal, was for the first time applied in Nieuwerkerk a/d IJssel, The Netherlands in 1980 during second type of experiment, namely the application of non-wovens under a road foundation. Measuring of strains took place in several sections during the time that foundation material was transported to the site by motorlorries.
Hence the loading was dynamic and strains have been continuously registered by means of recorders.
Dynamic strains amounting to 13 percent have been recorded. An example of a recorder trace is given in fig. 6.

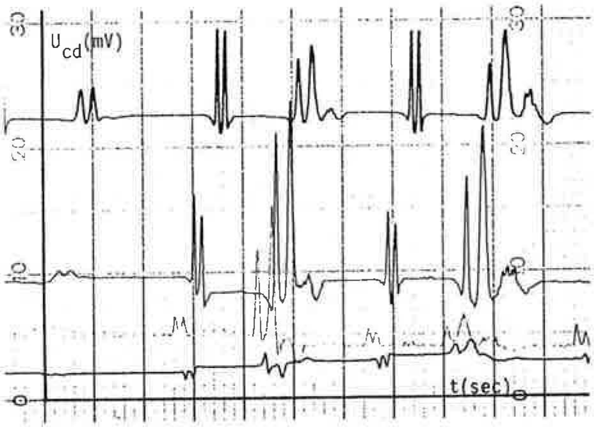

Fig. 6. Recorder trace of gauge value.

The value of U_{cd} changing with time, was afterwards simulated in a laboratory test, yielding the real geotextile strains as well as the corresponding forces.

It can be concluded that the developed measuring method is very well suited to the purpose of recording strains up to ca. 15% under field conditions.
The method can be used in cases where strain monitoring during construction is required to allow of assessing the permissible construction rate.