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Modelling and instrumentation considerations of a geogrid

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ABSTRACT: In this paper, similitude conditions concerning modeling of geosynthetic materials in *1g* and *Ng* conditions are discussed with an emphasis on geogrids. Secondly, instrumentation and calibration aspects of model geogrid with special type of tiny strain gauges for measuring tensile strength are examined. The geogrid layer was used as a reinforcement inclusion within the model clay liner subjected to non-uniform settlements in geotechnical centrifuge. The measured tensile strength and observations made during the centrifuge test were reported.

1 INTRODUCTION

A wide range of geotechnical problems can be investigated using physical modelling techniques and the evaluation of the behaviour of soil structures with geosynthetic inclusions is no exception. However, with the model tests at normal gravity the behaviour of soil mass could not be simulated properly because of the dominance of self-weight forces in geotechnical engineering. In order to replicate the gravity induced stresses of a prototype structure in a *1/N* reduced model, it is necessary to test the model in a gravitational field *N* times larger than that of prototype structure (Schofield, 1980). Geosynthetic materials, such as geotextiles and geogrid reinforcement elements have been successfully used in soil structures such as walls, slopes, embankments on soft soil and most recently in landfill liners. The reinforcement elements are mainly planar layers like geotextiles or uniaxial geogrids in the case of slopes and walls or biaxial geogrids for embankments on soft ground, pavements on weak subgrade, and landfill liners. Design theories have been developed alongside an increasing database of prototype, small-scale studies under *1g* and *Ng* conditions. A major difficulty encountered in model studies involving geosynthetic materials like geogrid is selection, modelling and instrumentation of ideal materials. In this paper, the modelling considerations of geosynthetic materials are presented for *1g* and *Ng* tests. The consequent effects which may arise for not using scaled-down geosynthetic materials, especially under *1g* conditions and necessity of standardization of miniature version of geosynthetic materials representing the bandwidth of commercially available prototype geosynthetics is brought out. Further, instrumentation and calibration aspects of model geogrid with strain gauges for measuring tensile strength were discussed. The measured tensile strength and observations made during the centrifuge test were presented.

2 MODELLING OF GEOSYNTHETIC MATERIALS

In physical modelling (both *1g* and *Ng*), it is assumed that the average particle size of soil used in the model and prototype structure is identical. In the case of studies pertaining to reinforced soil structures, contrary to soils the similitude condition does not allow the use of identical products in model and prototype studies. The scaling down of geosynthetic materials is essential in a small-scale physical modelling studies (both *1g* and *Ng* studies) in order to infer the correct response of prototype soil structure. Many investigators have attempted to model the geosynthetic reinforcement for understanding the behaviour of reinforced soil structures either at normal gravity conditions or at accelerated gravity conditions with sand/clay as interface. The characteristics of different modelled geosynthetic materials by various investigators for both *1g* and *Ng* studies are summarised in Table 1. The range of selected model materials includes weakened medical gauge to miniature version of commercially available prototype geosynthetic materials. As can be seen from Table 1, very few have attempted to consider modelling of geosynthetic materials in *1g* model tests. The reason could be attributed to the initial interest in understanding the behaviour of geosynthetic reinforced soil structures qualitatively. Geosynthetic materials to be scaled-down are primarily of two types (i) geotextile and (ii) geogrid. In the case of geotextile, typically two requirements were seen to be fulfilled (a) simulation of tensile strength-strain behaviour of model material and (b) thickness of model material [for e.g. Ovesen (1984), Taniguchi et al. (1988), Porbaha and Goodings (1994), and Zornberg et al. (1997)]. The model geotextile material was selected such a way that it is as thin as possible and exhibits low tensile strength for the defined strain limit. While modelling geotextile either for $1g$ or Ng studies, many investigators have also considered mass per unit area. With this, it should be possible to ensure the model geotextile material with low tensile strength and thickness. In the second type, at least ten to fifteen varieties of synthetic (many having different styles) geogrids are available commercially. They differ considerably in geometry and mechanical properties. The manufacturers attempt to vary the typical geometrical characteristics and tensile strength characteristics (as manufacturing process variable) in order to achieve a desired geogrid. As tensile strength characteristic of synthetic material is mainly dependent on the composition and type of raw material, it has become one of the manufacturing process variables. In addition, depending upon the type of geosynthetic reinforced soil structure being considered there are two more types, namely (i) uniaxial and (ii) biaxial geogrids. This complicates further to scale geogrids to the desired scale factor altogether. The properties of these geogrids are specified based on (i) rib cross-sectional area, (ii) grid opening size, (iii) tensile strength, and (iv) type of material composition (Fig. 1). Mitchell et al. (1988), and Springman et al. (1992) have modelled geogrids for Ng tests. While studying the deformation behaviour of reinforced clay liners subjected to non-uniform settlements in geotechnical centrifuge, Viswanadham (1996) have dealt in detail about the modelling aspects of geogrid. Perfect scaling-down of the prototype geogrid to the desired scale factor may not be feasible. However, the ideal geogrid for model studies needs to be selected by considering suitable model geogrid representing the bandwidth of prototype geogrid characteristics.

For tensile reinforcement (like geogrid) to be functional, not only the tensile strength-strain behaviour but also the reproduction of identical frictional bond behaviour between model and prototype must be achieved. By scaling down the prototype geogrid opening sizes to the desired scale factor in the model studies, there is a danger of loosing interlock between soil and geogrid (Fig. 1). In order to overcome this difficulty, it is required to consider modeling of frictional bond behaviour by scaling down the ratio of rib cross-sectional area and grid opening size (measured from centre to centre of ribs) by factor N (i.e., for example in longitudinal direction, $[b_l t_l/(a_t+b_t)]_m = [b_l t_l/(a_t+b_t)]_p/N$; $A'_m = A'_p/N$) and by

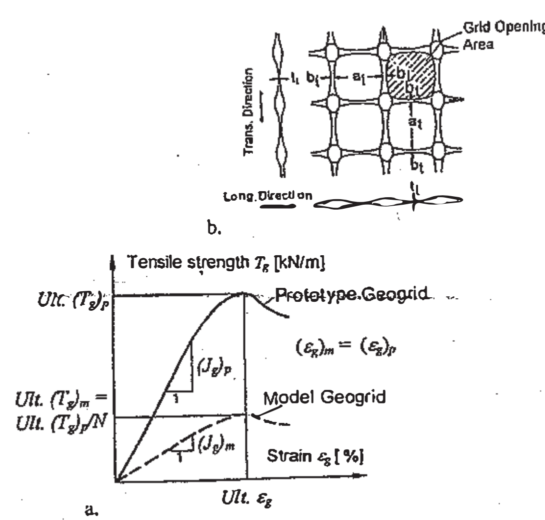

Figure 1. Idealised model geogrid characteristics.

maintaining identical percentage open areas of model and prototype geogrids ($f_m = f_p$). Whereas, $f = [(a_l a_t)/(a_l+b_l)(a_t+b_t)]$. Assuming that the tensile stresses in the geogrid with identical material characteristics in model and prototype (i.e. $\sigma_p = \sigma_m = \sigma$; suffix: m: model; p: prototype), the constitutive law of the geogrid $\sigma = E\varepsilon$ (where, E = modulus of elasticity of geogrid material), and identical geogrid strains in model and prototype $[(\varepsilon_g)_m = (\varepsilon_g)_p = \varepsilon]$ are valid, the scale factor for tensile strength of model geogrid T_g can be deduced for Ng modelling as follows:

Considering validity of $T_g = \sigma A'$ and using the above,

$$\frac{(T_g)_m}{(T_g)_p} = \frac{E\varepsilon A'_m}{E\varepsilon(NA'_m)} = \frac{1}{N} \qquad (1)$$

Correspondingly, the secant stiffness of the model geogrid shall be $1/N$ times the prototype geogrid stiffness (by using the validity of $T_g = J_g\varepsilon$). Based on the above mentioned modelling considerations, four model geogrids have been selected and their characteristics are summarised in Table 1 (see under No. 8). By considering above scaling laws for $1g$ studies, the tensile strength and secant stiffness of the model geogrid shall be $1/N^2$ times prototype geogrid tensile strength and secant stiffness respectively. Although, the scale factor will be low for $1g$ studies, it is required to consider scaled-down geogrid. As it otherwise ends up in over estimating the effect of reinforcement in interpretation of test results. However, small-scale physical modelling of geosynthetic soil structures tested at normal gravity has been used in the past to provide the insight into failure mechanisms qualitatively and very few have attempted to model the geogrid [for e.g. Love et al. (1987), Moghaddas-Nejad and Small (1997) and Pinto and

Cousens (1999)]. Love et al. (1987) has reported about the use of miniature version of geogrid for the first time as reinforcement inclusion in their *1g* model studies on granular fills on a soft clay subgrade. Similarly, Moghaddas-Nejad and Small (1997) have reported about their model track tests on the effect of geogrid reinforcement of pavements (N = 4). Further, Maghaddas-Nejad and Small (1997) have opined that the geogrid product used had a relatively small opening size and a small rib size (Table 1) and that in the prototype it would correspond to reinforcement with a larger grid size and a higher stiffness. However, as shown in Table 1, at 5 % strain the selected model geogrid is found to have a secant stiffness of 280 kN/m in longitudinal direction. By considering the scaling laws, it should have been 17.5 kN/m (i.e. $280/4^2$). This suggests the essentiality of scaling-down of geosynthetics even for *1g* model studies.

3 INSTRUMENTATION OF GEOGRIDS

Very few have reported on the use of strain gauges in centrifuge model testing glued to synthetic materials, such as, geogrids, soft fabrics. The use of high performance Cu-Ni strain gauges were earlier reported by Springman et al (1992) to measure the load and strain independently in the centrifuge tests.

In the present study, a model geogrid layer was used as a reinforcement layer within the model kaolin clay liner subjected to non-uniform settlements using trap-door arrangement in centrifuge. As the bending stiffness of the reinforcement layer is negligible, it is assumed that the reinforcement layer follows the deformation profile attained by clay liner.

At the onset of non-uniform settlements, the model geogrid layer is subjected to strain due to (i) change in length and (ii) curvature. The details concerning model test package are discussed in detail by Viswanadham (1996). In this paper, the results and observations made on the deformation behaviour of kaolin clay liner reinforced with instrumented model geogrid are reported. The model geogrid MGG1 was selected for instrumentation and its characteristics can be seen from Table 1 (No. 8). A special gauge type GFLA-3-70 (with dimensions 3 mm in length, 2.3 mm in width and with a backing of 9.5 x 4 mm) supplied by M/s Europavia Gmbh, Germany was used. The procured strain gauges are having a nominal resistance of 120 Ω, gauge factor [k-factor] of 2.13 and with strain limit of 3%. The calibration of strain gauges fixed to the model geogrids is found to be complex. This is because of the non-linear behaviour of the model geogrid. It is interesting here to note that in addition to the non-linear behaviour of the geogrid material at large strains, the stress-strain

Table 1. Summary of characteristics of different modelled geosynthetic materials.

No.	Model, Material type & Composition		N	Material characteristics							
				a_l [mm]	a_t [mm]	b_l [mm]	b_t [mm]	t [mm]	f [%]	$\#(T_g)_u$ [kN/m]	$(\varepsilon_g)_u$ [%]
1.	*Ng*	Geotextile -Cotton	50	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	0.2	4.8
2.	*Ng*	Geotextile -70% Nylon+ 30% PET	50-55	--[a]	--[a]	--[a]	--[a]	0.217	--[a]	13.2-13.6	38-29
3.	*Ng*	Geotextile	40	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	0.066	10
		Geogrid-Plastic	40	1	1	0.15	0.15	0.15	85	0.53	18
4.	*Ng*	Geogrid -PET	40	3.3	3.4	0.7	0.7	--[a]	68	18	16
		Geogrid-PP	40	5.7	6.3	0.4	0.4	--[a]	88	3	23
		Geogrid-PP	40	5.5	7.1	0.2	0.2	--[a]	94	1	12
5.	*1g*	Geotextile-PET	10	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	55	79
6.	*Ng*	Geotextile - 60% PET+40 % Rayon	40	--[a]	--[a]	--[a]	--[a]	0.0006	--[a]	0.18	20
7.	*1g*	Geogrid-PP	4	40	28	3	3	0.9	82	14 at 5% strain	
8.	*Ng*	Geogrid -PET (**MGG1**)	50	3.4	3.7	0.46	0.91	0.16	71	13.2	27
		Geogrid-FG+PVC(C)	50	1.4	1.3	0.32	0.28	0.13	65	9.5	11
		Geogrid-PP	50	3.4	3.8	0.1	0.11	0.02	89	1.2	30
		Geogrid-PP	50	5	5	0.16	0.25	0.16	93	2	55
9.	*Ng*	Geotextile-100% PET	100	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	0.063	18
		Geotextile - 60% PET+40%Rayon	100	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	0.119	29
10.	*1g*	Geotextile-PET	5	--[a]	--[a]	--[a]	--[a]	0.3	--[a]	2.7-3.5	15

1) Ovesen (1984), 2) Taniguchi et al. (1988), 3) Mitchell et al. (1988), 4) Springman et al. (1992), 5) Palmeria & Cunha (1993), 6) Porbaha & Goodings (1994), 7) Moghaddas-Nejad and Small (1996), 8) Viswanadham (1996), 9) Zornberg et al. (1997), and 10)) Pinto and Cousens (1999).

PP = Polypropylene; PET = Polyester; FG = Fiber Glass; PVC (C) = PVC coated; FRP = Fiber Reinforced Plastic;
--[a] Data not available/Not applicable; # Longitudinal direction only.

relationship of the material subjected to loading and un-loading cycles is also significant. The strain gauges are to be fixed to the uniform hardened basematerial. The addition of the base material to the geogrid will influence the stiffness of the geogrid slightly. As a first step, the influence of uniformly hardened epoxy adhesive on the load-strain behaviour of the model geogrid was studied. Figure 2 presents the tensile strength - strain behaviour of the model geogrid with and without epoxy base strips. Three no's of epoxy base strips (of width approx. 18 mm and 2 mm in thickness) were spaced equally within the gauge length. It can be seen from the presented results that the presence of epoxy base strips has little influence at lower strain levels. However a marked influence of epoxy base strips (more than one) was noticed at higher strain levels (i.e. > 4 %). It is necessary to carry out calibration tests in order to study the strain gauge response to the loading and reloading cycles of the geogrid. So it is required to calibrate every new model geogrid with strain gauges meant for the centrifuge tests. It is necessary to investigate the strain gauge response to the defined loading cycles in order to calibrate the model geogrid. This enables to arrive at calibration factors, which can be used to analyse the strain behaviour of the model geogrid in centrifuge test results.

As shown in Fig. 3, the calibration tests were carried out with strain gauges glued on to the model geogrid MGG1. The selected model geogrid was cut to desired size such a way that it is convenient for calibration and subsequent use in centrifuge model test. The epoxy base material was spreaded uniformly by hand over ≈ 6 apertures wide (18 mm).

After spreading the half portion, a very thin Teflon foil strips were used to reinforce the matrix in the tensile strain direction and the Teflon foil strips are overlaid again with epoxy matrix and left for curing at room temperature for about 12 hours (Fig. 4). To prevent the flow of epoxy base material be-

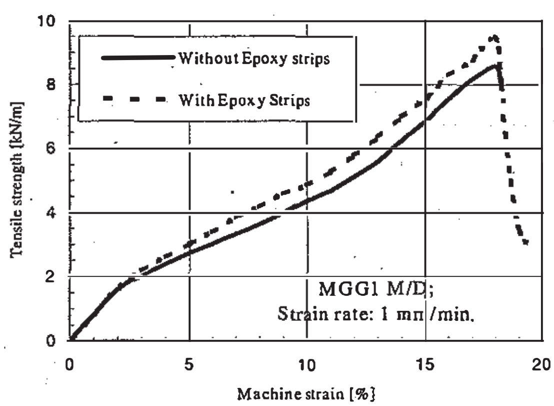

Figure 2. Tensile strength vs. strain behaviour of MGG1 with and without epoxy strips.

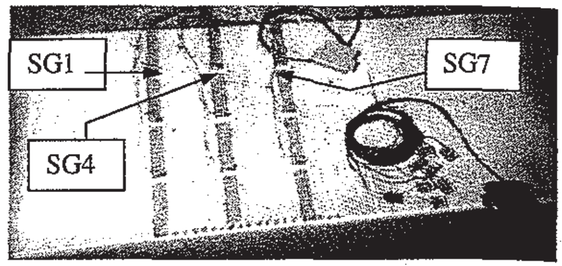

Figure 3. Instrumented model geogrid.

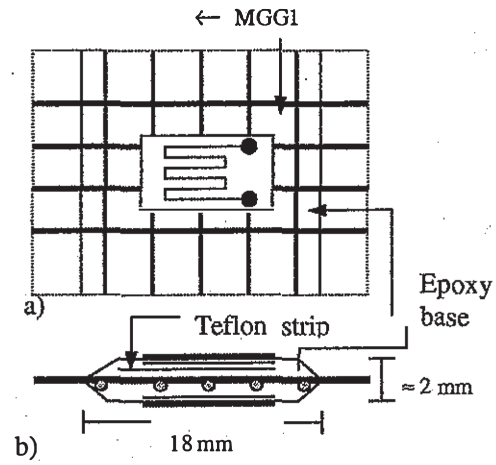

Figure 4. Details of strain gauge on model geogrid.

fore curing, a temporary restraint was provided. The edges of epoxy strips were smoothened (Fig. 4b) to prevent any influence on the soil-geogrid frictional interaction. After smoothening the surface, the strain gauges (in pairs) were glued centrally to the upper and lower surfaces of the epoxy strips using a Cyanoacrylate adhesive and the electrical connections were given in such a way that the bending effects are eliminated. Each strain gauge is supplemented by the dummy strain gauges (fixed on both the upper and lower surfaces of the Perspex glass piece), which are located in the vicinity of the strain gauges fixed on to the geogrid. The dummy gauges are to nullify the effects due to temperature. The prepared model geogrid sample is fitted within the grips of the specially fabricated roller grips. With this arrangement, it is possible to prevent any damage to the model geogrid. The model geogrid was calibrated through a load-controlled approach and subjected to five loading and unloading cycles. During the calibration, the model geogird was subjected to a maximum loading of 1.25 kN/m (i.e. 14 % of ultimate tensile strength of model geogrid with three epoxy strips spaced at 100 mm c/c) in small increments. In each loading step, a waiting period of 10 minutes approximately was maintained to observe the influence of time. The response of strain gauges is observed to stabilise after completion of two load

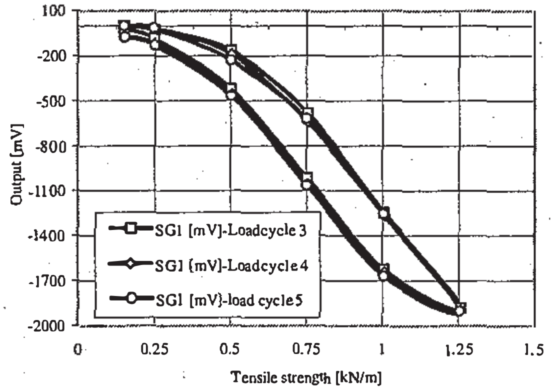

Figure 5. Calibration curves for strain gauge on the model geogrid.

ing-unloading cycles. This could be attributed to the non-linear characteristic of model geogrid material.

Hereafter, the response of strain gauges for the last three cycles was considered for the analysis. Typically, Strain gauge response (SG1) versus tensile strength is shown in Fig. 5 for the last three loading-unloading cycles. The reproducibility of identical response can be noticed. The initial curvature during each loading cycle suggests the non-linear variation of the model geogrid material. This is observed to be predominant at lower tensile strength levels and once after subjected to adequate loading variation of strain gauge response is found to be linear. Identical behaviour is found to observe for other strain gauges also, except with different slopes of tensile strength-strain gauge response curves.

Considering the above aspects, for interpreting the geogrid tensile strength through centrifuge test, the calibration factors obtained within the linear range are used. Based on the calibration tests carried-out with the defined strain levels and limited studies made, the measuring accuracy of the strain gauge response with respect of tensile load is of the order of $\pm$ 0.1-0.15 kN/m. However, by considering the reproducibility of calibration tests in this study for further investigations the strain gauges can be used to measure in-plane tensile strength characteristics of the embedded geogrid. It is required to calibrate the model geogrid by loading and unloading cycles till the reproducible response is achieved.

4 RESULTS AND DISCUSSION

Figure 6 presents a portion of deformed 25 mm thick model clay liner at the end of the centrifuge test. The reinforced clay liner was subjected to a maximum central settlement a of 25 mm in steps of 5 mm with a settlement rate of 1 mm/min. Before initiation of non-uniform settlements in flight, the clay liner is al lowed to consolidate for about 4-5 hours. Between

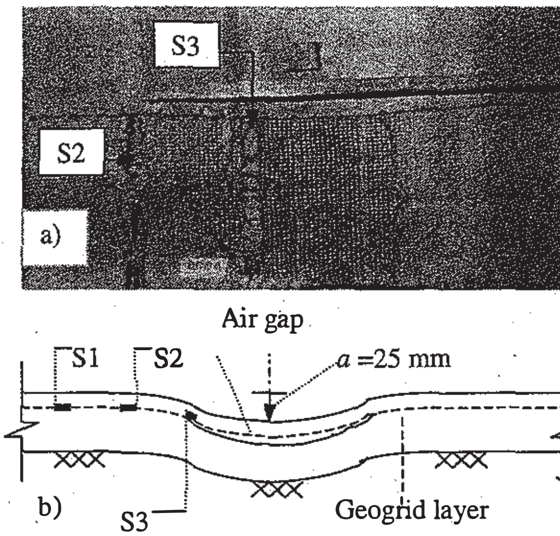

Figure 6. Deformed model geogrid at the end of centrifuge test.

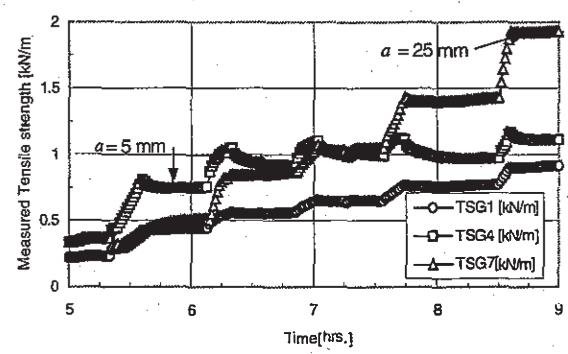

Figure 7. Measured variation of tensile strength in model geogrid with time [Model dimensions].

each settlement increment of 5 mm a waiting period of 30 minutes is maintained. The schematic deformation profile of model geogrid is shown in Fig. 6b with an air gap in the central region. The formation of air gap is observed to take place after attaining a central settlement of 15-20 mm. This is attributed to participation of tension membrane effect at large settlement differences (Viswanadham, 1996). The measured variation of tensile strength in the model geogrid with time and for each settlement increment is given in Fig. 7. Typically, the response of SG1, SG4 and SG7 (refer Fig. 3) are presented. With an increase in central settlement a, marked increase in tensile strength can be noted. At $a =$ 0 mm the model geogrid seems to have a tensile strength of the order of 0.25 kN/m. This could be due to adoption of calibration factors obtained from slope of linear portion of tensile strength-strain gauge response curves. The strain gauge SG4 is located in maximum curvature zone (i.e. at S2 in Fig. 6b) and it is found to experience high tensile strength till it attains a central settlement of 15 mm and thereafter the strain gauge SG7 was found to mobilise high tensile strength (Fig. 7). This establishes the participation of tension membrane effect resulting due to an increase in stiffness of the instrumented model geogrid after attaining a limiting strain.

5 CONCLUSIONS

Based on the above considerations, an attempt has been made to bring out the significance of scaling-down of geosynthetic materials for 1*g* and *Ng* tests. However, in order to model soil-geosynthetic behaviour satisfactorily, there is a substantial requirement of standardisation of model geosynthetic materials for studies pertaining to the beahviour of reinforced soil structures. The instrumentation and calibration aspects of model geogrid reveals the following; (i) It is required to calibrate the model geogrid by loading and un-loading cycles till the reproducible response is achieved and (ii) Strain gauges can be used to measure in-plane tensile strength characteristics of embedded geogrid. However, the influence of base material on the tensile strength-strain behaviour of the geogrid cannot be ruled out.

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