Study of OCR of loess by flat dilatometer

Etude de RSC du loess au moyen du dilatomètre plat

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SYNOPSIS The paper presents data from an investigation of collapsible loess soils in Northern Bulgaria by flat dilatometer in regard to the determination of the extended overconsolidation ratio (EOCR). It has been found that in natural loesses as well as in some compacted loesses, layers with extremely low values of horizontal stress and of EOCR occur. This condition is interpreted as a state of underconsolidation of the soil with respect to the present overburden pressure.

INTRODUCTION

The overconsolidation ratio (OCR) is a soil parameter characterizing the stress history of a soil with respect to the existing stress state. It is of essential importance in regard to the correct prediction of the deformation of the subsoil and is generally defined by the well known equation:

$$OCR = p_c'/p_o' \qquad (1)$$

where p_c' is the maximum effective overburden pressure which had ever existed in the past at any level in the soil deposit, and p_o' is the corresponding present overburden pressure. The value of p_c' is generally determined by one of several techniques from oedometer test data. Results of confined compression tests on undisturbed soil samples show that some soils which have not undergone a geologic unloading may also show an effect of overconsolidation. This is manifested by a value of the pressure p_c' at the break in compression curve greater than p_o' essentially the same behavior exhibited by geologically preconsolidated soils. This effect can be caused by secondary consolidation, desiccation, or the development of rigid structural bonds. Obviously, in such cases the presence of $p_c' > p_o'$ would not mean that the coefficient of earth pressure at rest $K_o > 1$ but often enough the former inequality would reflect essential peculiarities in the mechanical behaviour of the given soil.

Marchetti (1980a) investigated soils of this type in situ with the flat dilatometer (DMT) and observed a discrepancy between the values of OCR determined in situ and those expected for geological reasons, the former being always higher than the latter ones. From the characterization Marchetti had given to the soils investigated it is evident that these had been deposits of normal, and in several cases, also of considerable density, which would indicate that they have a low sensitivity. Tests carried out in sensitive Scandinavian clays (Marchetti, 1980b), had given questionable results most probably because of liquifying of the soil facing the membrane of the blade during penetration into the ground.

The writers made it their aim to investigate the values of EOCR in collapsible loess soils using the flat dilatometer of Marchetti. As it is well known, these soils are distinguished by considerable sensitivity, but because of their low saturation in the natural state they do not liquify from disturbance of the soil structure. The paper presents results from tests carried out at several sites in the loess province of Northern Bulgaria.

DETERMINATION OF OCR BY FLAT DILATOMETER

A detailed description of the DMT and the test procedure were presented by Marchetti (1980b). It is noted here only that the response of the soil is measured twice: at pressure required to just lift the membrane from the face of the blade and at pressure required to move the membrane center 1.00 mm into the soil. The two readings, first corrected for membrane stiffness, are designated p_o and p_1 respectively and are used to obtain the DMT parameters through the following equations:

$$\text{Material Index } I_D = (p_1-p_o)/(p_o-u_o) \qquad (2a)$$

$$\text{Horizontal Stress Index } K_D=(p_o-u_o)/p_o' \qquad (2b)$$

$$\text{Dilatometer Modulus } E_D=34,6(p_1-p_o) \qquad (2c)$$

where u_o is the pore water pressure prior to the blade insertion to the depth concerned, usually assumed to be hydrostatic.

Marchetti (1980a) has made a distinction between "normal" and "abnormal" soil deposits. "Normal" deposits are described as those in which the horizontal stresses between soil particles are "normal" and correspond to simple one-dimensional loading or unloading. On the other hand, "abnormal" deposits are the deposits in which the horizontal stresses between the soil particles, including the attraction stresses, are in excess (positive or negative) of the "normal" horizontal stresses.

From DMT investigations of "normal" clay deposits, Marchetti (1980a) establishes a well defined correlation between OCR and K_D. On the other hand for the investigated "abnormal" deposits he found that the K_D values are higher than in "normal" deposits with the same geologic OCR. Therefore, if the "normal" correlation between OCR and K_D is used and entered for the "abnormal" soils with higher values of K_D, correspondingly higher values of OCR would be obtained. Since these values of OCR reflect the influence of factors other than the simple loading and unloading, Marchetti termed them "extended" OCR (EOCR) values.

Marchetti and Crapps (1981) later differentiated the correlation between OCR and K_D as a function of I_D, or the type of the soil material, and calculate OCR as:

$$OCR = (mK_D)^n \qquad (3)$$

where $m = 0.5 + 0.17p$; $n = 1.56 + 0.35\,p$ and $p = (I_D - 1.2)/0.8$. The latter equation is valid for $1{,}2 \leq I_D \leq 2$ while for $I_D < 1{,}2$ and $I_D > 2$ these limit values are used for which $p=0$, respectively $p=1$ would be obtained. In this paper equation (3) was used to obtain the values of OCR or EOCR respectively.

TEST RESULTS

Minkov (1968) has shown that the collapsible loesses covering a large part of the territory of North Bulgaria have their origin in accumulations of material of mostly silt size, transported by the wind. This accumulation had taken place in semiarid conditions which caused an early development of rigid capillary and cementation bonds at individual particle contacts. With the relatively low natural water content which is characteristic of collapsible loess soils, structural bonds have been able to prevent the consolidation or compression of the material thus keeping it in a low density even at considerable depth below the ground surface, i.e., under considerable overburden pressure. Because of this phenomenon, these particular type of soils are characterized by underconsolidation with respect to the overburden pressure which is, according to Denissov (1961), their most typical mechanical property. This property reveals itself at increasing moisture content up to a point at which the water-soluble rigid bonds fail, causing subsidence of the ground and restoration of the retained consolidation of the loess soil.

In the territory of North Bulgaria, Minkov (1968) distinguishes up to 6 loess horizons with as many as 5 horizons of fossil soils with depth. At the DMT soundings interpreted in this work, the second fossil soil has been reached as can be seen from the stratigrafic columns shown in the figures. Geologically the Bulgarian loess soils are normally consolidated. All the soundings were made in typical loess, characteristic of the surroundings of Russe with the exception of the one at Kozloduy which is in loesslike sand.

Russe, Site 1, Natural Loess

Comparing the physical characteristics of the soils with the DMT data, no specific relationships are readily apparent excepting the decrease of p_o, p_1, K_D and EOCR* and the increase of I_D met over the middle of L_2, corresponding to the minimum values of w and S_r and to the maximum values of ρ_d. However, at the bottom of L_2 where w and S_r have almost the same values, p_o and p_1 reach their maximum and K_D and EOCR effectively increase while I_D decreases. The most important point here is the presence of extremely low values of K_D and EOCR in the depth ranges of L_2.

Russe, Site 1, Compacted Loess

This DMT sounding was located about 30 m from the first one where the ground had been compacted by 12 blows of a heavy tamper. Despite the imperfect coincidence of the stratification at the two points of sounding, Figure 2 indicates that down to a depth of 3 m under the compacted ground surface the values of the DMT parameters have strongly increased which is obviously a result of the compaction. Of special interest to our topic is the dramatic increase of EOCR in the compacted zone while at a depth of 7 m it drops again to an extremely low value. The writers believe that the upper, compacted part of the profile represents an example of "abnormal" soil of the type described by Marchetti (1980a) characterized by higher values of K_D and EOCR and of the horizontal stresses, respectively.

Russe, Site 2, Natural Loess

From a comparison with the natural loess of Site 1 one can see that the profiles of the soil characteristics are quite similar but with certain "extension" downwards at Site 2, Fig. 3. As to the profiles of the DMT parameters, similarity can be observed mainly in the upper layers. In the ranges of L_2 they display quite different configurations. In particular the extremely low values of K_D and EOCR are met here

*Here and further the parameter determined by Equation 3 is termed EOCR since it is, as a rule, greater or less than 1 which is the OCR-value for the investigated normally consolidated loess soils.

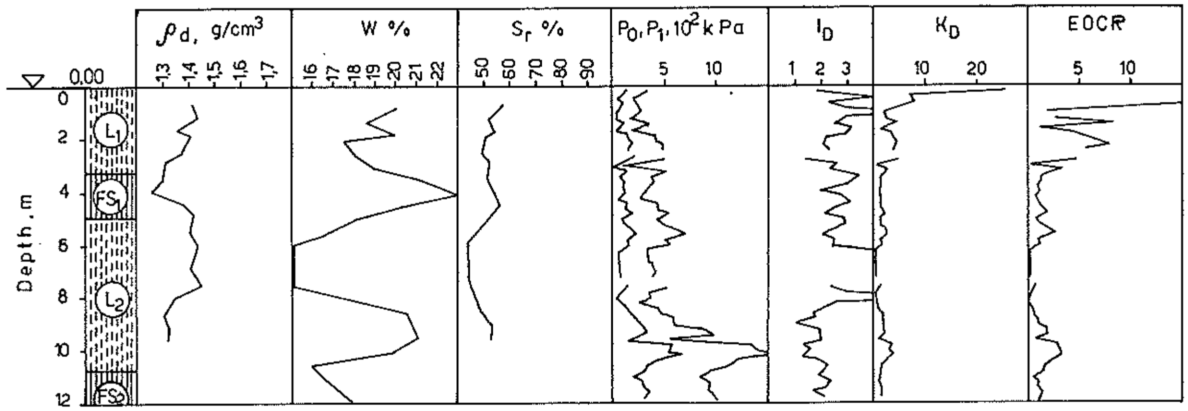

Fig. 1 Soil Data and Dilatometer Test Results at Russe, Site 1, Natural Loess

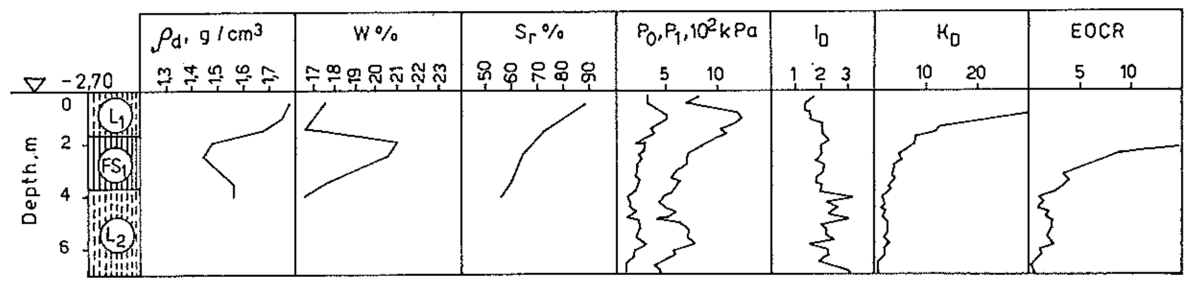

Fig. 2 Soil Data and Dilatometer Test Results at Russe, Site 1, Compacted Loess

in about the lower one-third of this layer and correspond to low values of ρ_d and relatively high ones of w and S_r.

Russe, Site 2, Compacted Loess

The sounding was located at about 10 m from the first one in an area which five years earlier had been compacted by deep explosions and additional moistening, reaching the bottom of L_2, as a part of a larger experiment. As a result of the compaction, the surface of the treated area had subsided about 1 m. Compared with the DMT data of the natural loess one can see in Figure 4 that here the extremely low values of K_D and EOCR are located in the same depth ranges (the lower half of L_2), and are very close to those of the natural loess, but in this case they are connected with abruptly decreased values of p_1 and I_D. At the same time, the profiles of ρ_d, w and S_r retain their configuration accompanied by a considerable increase in their absolute values. The compaction effect manifests itself most markedly in the upper part of L_2 where the highest values of ρ_d and relatively low ones of S_r are met.

Russe, Site 2, Steppe Limpet

This sounding was made in the vicinity of the bottom of a pronounced Steppe Limpet some 60 m away from the sounding in natural loess. A Steppe Limpet is a natural upland closed depression characterized by a lowering of the surface elevation in collapsible loess grounds. The Steppe Limpets had developped as a result of the concentration of surface water in primary lowerings of the loess ground surface and of its subsequent infiltration. In the course of time this process has caused considerable changes in the chemical composition as well as the natural consolidation and the natural stress state of the ground within the limits of the Steppe Limpet. Such a marked change of the properties of the soil and of the ground are undoubtedly of interest to our topic since it offers a comparison with the natural loess. It may be seen from Figure 5 that in this case the profiles of the soil characteristics are quite uniform with depth and with markedly higher absolute values of ρ_d, w and S_r. Considering the profiles of the DMT parameters the writers are surprised to find that they are not without similarity to those of the hydro-explosive compacted loess of Figure 4. Especially characteristic in this respect is the last increase and the following abrupt drop of p_1 and I_D at a little distance over the middle of L_2. It is worth noting also that in this case the relations between the soil characteristics and the DMT profiles compare fairly well with the corresponding relations of the hydro-explosive compacted loess especially for the low part of the profiles. However this sounding is clearly distinguished from the other two soundings conducted at this site by the markedly higher values of the DMT parameters and by absence of extremely low values of K_D and EOCR. It may be assumed that also in this case the upper part of the profiles represent an "abnormal" soil of the type

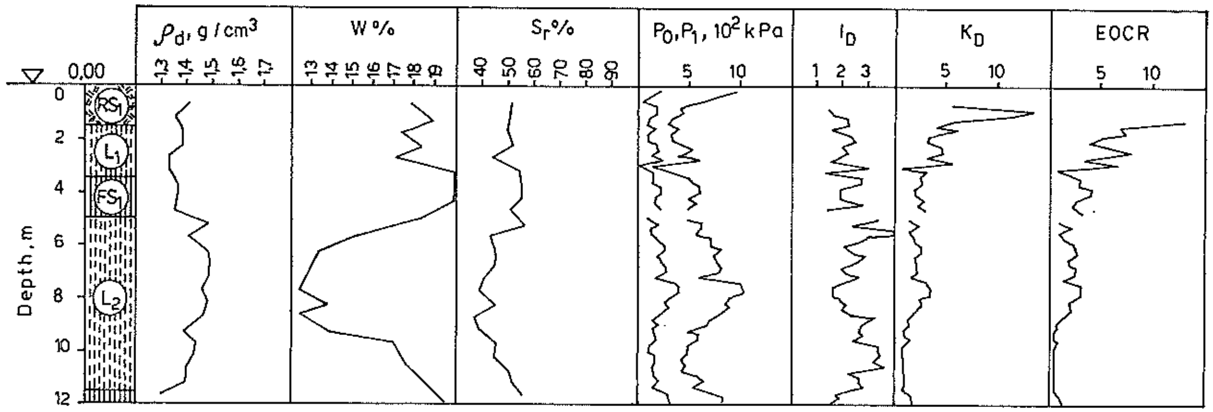

Fig. 3 Soil Data and Dilatometer Test Results at Russe, Site 2, Natural Loess

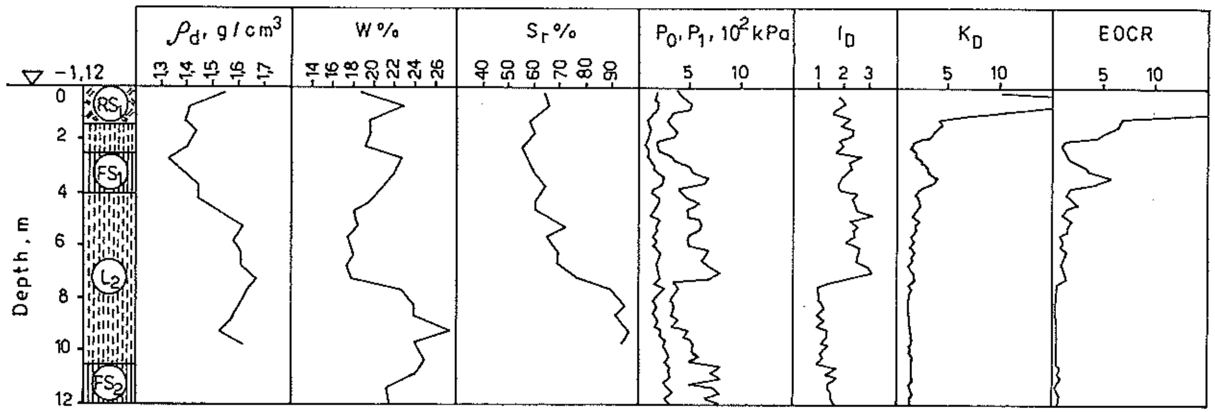

Fig. 4 Soil Data and Dilatometer Test Results at Russe, Site 2, Compacted Loess

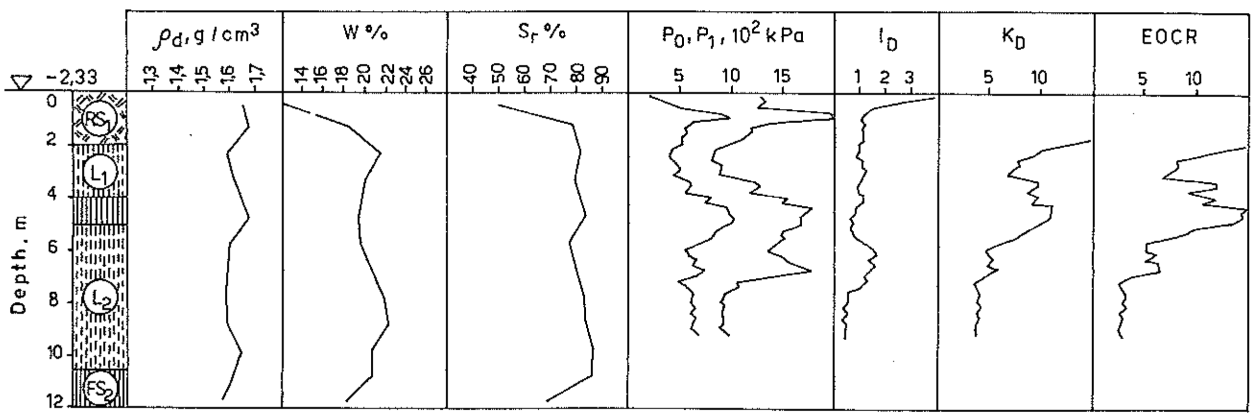

Fig. 5 Soil Data and Dilatometer Test Results at Russe, Site 2, Steppe Limpet

described by Marchetti (1980a).

Kozloduy, Natural Loesslike Sand

Unfortunately, at this site a boring for description of the stratification and extraction of soil samples could not be made. According to Minkov (1968) this type of soil has very limited distribution in Northern Bulgaria. It is characterized by marked uniformity; it has only one slight fossil soil horizon, a grading dominated by a fine sand fraction at almost full absence of clay fraction,, weak structural bonds and a relatively low collapse potential. The profiles of the DMT parameters confirm to some extent this characterization. To begin with one can observe that up to 10 m below the ground surface p_o and p_1 increase uniformly while I_D and K_D show little variation up to this depth. The profiles of I_D and K_D are quite similar in configuration to the corresponding profiles of the medium-fine loose sand of the hydraulic fill at Damman tested by Marchetti (1980b). However while the K_D and

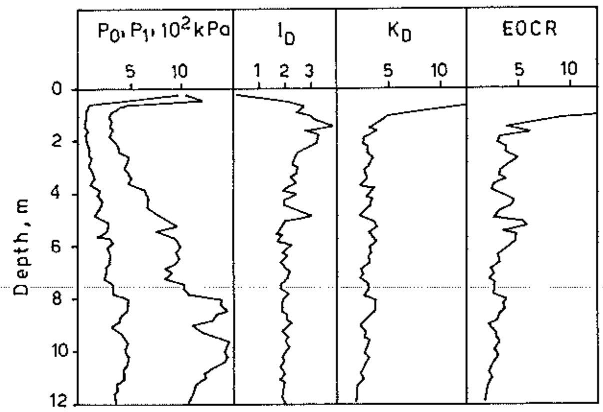

Fig. 6 Dilatometer Test Results at Kozloduy, Natural Loesslike Sand

EOCR values of the Damman sand correspond well to the normal consolidation of the sluiced sand, those of the loesslike sand from Kozloduy are more characteristic of a slightly preconsolidated soil. The soil had not undergone a geological unloading and because of its specific character it is hardly likely that a noticeable secondary consolidation could take place. One possible explanation of the obtained DMT data may be that because of its markedly uniform grading the loesslike sand in the vicinity of the blade would exhibit relatively low deformability due to dilatancy.

DISCUSSION

From the description of the sounding results in the preceeding section it may be concluded that the response of the soil to the insertion of the instrument is caused by many different factors, in one case some of them prevailing, in another case -others. In the following discussion an attempt is made to analyze the working conditions of the blade's membrane during the stages of penetration and inflation.

Marchetti (1980a) considers that in "abnormal" deposits the geostatic stresses and stresses caused by other factors are added. As most important among the factors causing additional stresses Marchetti considers the so called "attraction" between the soil particles. Such "attraction" can arise as a combined or individual effect of different processes such as aging, thixotropic hardening, electro-chemical phenomena, etc. called by Marchetti as a whole "cementation processes". As to the soils treated in the present paper the attraction is also practically a factor of importance which is why the writters wish to concern it in some more detail. First of all it is necessary to distinguish the nature of the additional horizontal stresses of different origin united by the term "attraction". In the case of aging caused by creep (secondary consolidation) active additional horizontal pressure may arise in the soil deposit. This pressure will thus act on the membrane of the instrument during the stages of penetration and of inflation. However, the development of structural bonds as a result of thixotropic hardening of electrochemical processes will only reduce the soil deformability. Therefore, during the penetration of the blade additional passive pressure will arise on the membrane, its actual value depending on the soil strength and the tendency toward local compaction caused by the penetration of the blade.

With the collapsible loess soils, which are of low density, relatively low strength, and retained secondary consolidation, one may expect that both the active and passive pressure will be considerably lower than in the compact, heavily preconsolidated soils cited by Marchetti (1980a) as "abnormal". What is more, according to the hypothesis of the senior writer (Hamamdshiev, 1981) in highly porous, brittle soils of the type of collapsible loesses, in their natural state, i.e., before penetration, effective horizontal pressures are lower in comparison with those in the "normal" normally consolidated soils which might be expected at greater depth. This is due to the progressive failure of the brittle bonds under the action of an increasing overburden pressure and the shifting of the soil particles into the adjoining pores. According to this hypothesis the reduced horizontal effective stresses, respectively a K_o-profile which decreases with depth tending to K_A can serve as an unique phenomenological indication of a state of underconsolidation. As mentioned above, the DMT soundings have proved the existence of deep sections in the ranges of L_2 with very low values of p_o, K_D and EOCR. In fact they are not absolutely correct being obtained by extrapolation of correlation (3) which is valid only for EOCR > 0.8 (Marchetti and Crapps, 1981). Nevertheless it is quite clear that they are less than 0.8 which would characterize the tested soils as "abnormal" in a different way compared with those described by Marchetti (1980a). As to the hypothesis of Hamamdshiev and the concept of underconsolidation of the collapsible loess soils the above finding supports this without being able to prove it. The DMT results are not able to differentiate to what extent the low values of p_o are due to the effects accompanying the penetration of the blade on one hand, or to the possible reduction of the natural horizontal stresses on the other. In this respect an independent determination of the in situ horizontal stresses by an appropriate method would be extremely useful.

Marchetti (1980b) does not aim by DMT the measurement of the actual horizontal stresses in the natural ground. As to the determination of the conventional mechanical parameters of the soils, he means that the influence of the disturbance caused by the penetration of the blade may be reduced to a tolerable value through regression between the DMT parameter values and the corresponding laboratory values of the former ones. Marchetti makes an exeption only of the sensitive soils because of their great and indeterminable structural changes.

However since the blade thickness of DMT is considerable (14 mm) an extended disturbed zone around the blade may be expected also in cases of unsensitive soils. Thus Delatometer measurements would reflect only the disturbed state of the soil tested, no matter if the soil is sensitive or not. If this is true it may be expected that the established correlations will hold true also for sensitive or cemented soils provided that realistic readings can be made. Nevertheless the validity of the correlations for markedly cemented soils such as the collapsible loesses has to be verified by comparison with corresponding values of the conventional parameters obtained in the laboratory. Such a verification is in course.

CONCLUSIONS

1. The Dilatometer Test is an versatile and useful tool for in situ measurement of properties of collapsible loess soils which otherwise are difficult to sample.

2. Results of DMT tests conducted in collapsible loess soils show that in the DMT K_D- and EOCR- profiles sections of extremely low values were found. They characterize an "abnormality" of a different type compared to that observed by Marchetti (1980b). The writers feel that it may be interpreted as a state of underconsolidation.

3. The values and the distribution of the natural horizontal stresses in the ground are of critical importance for the classification of the natural consolidation state thus a direct measurement carried out in parallel to the DMT sounding would be of great use to the interpretation of the DMT data.

4. There are prospects that the correlations established for "normal" soils will hold true also for some cemented soils. This latter proposition had to be verified experimentally.

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