

Geosynthetics

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GIROUD-HAN DESIGN METHOD
Development and calibration

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The Giroud-Han design method for geosynthetic-reinforced unpaved roads

By J.P. Giroud and Jie Han

Since its publication in 2004, the Giroud-Han design method for geosynthetic-reinforced unpaved roads has received considerable attention from the geosynthetics industry. This article is the first of two that provides practical information for the users of the method as well as for those who want to learn about the method.

Introduction

The Giroud-Han (G-H) design method provides a design tool to determine the thicknesses of unreinforced and geosynthetic-reinforced aggregate bases for unpaved roads over soft subgrade. The method was published in two parts (Giroud and Han, 2004a, b) in the *ASCE Journal of Geotechnical and Geoenvironmental Engineering*.

The G-H method replaces the widely used method published by Giroud and Noiray (1981) and has been included in the updated "Geosynthetic Design and Construction Guidelines" manual by the Federal Highway Administration (FHWA, 2008).

Development of the G-H method was a long and complex effort in the late 1990s and early 2000s. The length and complexity were justified by the authors' desire to openly provide all details and calculations pertaining to the development of the method. However, the need for a summary of the method has been expressed. This article presents a summary of the method's features.

Even though the G-H design method has been adopted by consultants and geosynthetic manufacturers, a number of issues have arisen, which are clarified in this article. In particular, this article clearly indicates the equations that are generic—and can be used with any geosynthetic with appropriate calibration—and the equations that were calibrated for specific geosynthetics. This distinction between generic and calibrated equations is crucial because it was not clear to some readers of the original publications of the G-H method.

Also, the calibration steps were not easy to follow due to the length and complexity of the original papers. In this article, they are presented in a concise manner.

Definitions pertinent to unpaved roads

Unpaved roads typically consist of an aggregate layer (often called "base course" or simply "base") resting on the subgrade. When a geosynthetic is used in an unpaved road, it is generally placed at the base/subgrade interface. The use of geosynthetics in unpaved roads is a mechanical stabilization technique that is different from chemical stabilization. In mechanical stabilization, the base is improved via

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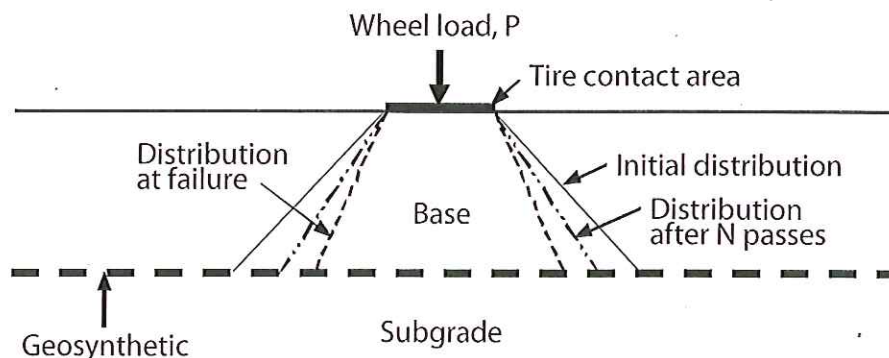


FIGURE 1 Stress distribution angle

the inclusion of a geosynthetic layer (or layers) and the aggregate remains unbound. Chemical stabilization involves inclusion of chemicals (e.g., lime, cement, binders) to bind aggregate materials or the subgrade soils.

It is important to distinguish between aggregate that is bound (as a result of chemical stabilization) and aggregate that is unbound. In this article, only unpaved roads constructed with unbound aggregate are considered. These roads can be either unreinforced or reinforced using geosynthetics. The term *reinforced* is equivalent to *mechanically stabilized* throughout this article.

The use of the terms *reinforced* and *reinforcement* in the context of unpaved roads does not imply that the geosynthetic simply adds force (i.e., simply adds its strength) to the unpaved road structure. As shown in the original publication (Giroud and Han, 2004a), a geosynthetic improves an unpaved road through complex mechanisms that mostly do not involve the strength of the geosynthetic per se. Therefore, in the context of unpaved roads, *reinforced* and *reinforcement* should be regarded only as convenient terms established by tradition.

Development of the generic equation of the Giroud-Han method

The G-H method can be used for the design of both unreinforced and geosynthetic-reinforced unpaved roads constructed with unbound aggregate.

In the development of the G-H method, the stresses at the interface between the base and subgrade are estimated using a stress distribution angle (Figure 1). The effect of base stiffness on the stress distribution angle is quantified using an approximate relationship between the stress distribution angle and the base to subgrade modulus ratio based on the classical Burmister's two-layer elastic solution (Burmister, 1958).

In the field, the stress distribution angle decreases progressively because of the progressive deterioration of the base due to cyclic loading resulting from trafficking. Laboratory tests by Gabr (2001) on unreinforced bases and on bases reinforced with biaxial geogrids, have led to a linear relationship involving the stress distribution angle and $\log N$, where

N is the number of load applications (i.e., the number of axle passes in the field). This relationship has recently been verified by Qian et al. (2011) for geogrids with triangular apertures.

The G-H method takes into account the progressive decrease of the stress distribution angle with a term $k \log N$, where k is a dimensionless parameter that depends on the radius of tire contact area (which is assumed to be circular), the base thickness, and the geosynthetic. Indeed, the inclusion of the geosynthetic at the base/subgrade interface reduces the deterioration rate of the base; as a result, the rate of decrease of the stress distribution angle is reduced.

As the stress distribution angle decreases, the maximum vertical stress at the base/subgrade interface increases. Bearing capacity failure of the subgrade occurs when the stress distribution angle decreases to a point where the stress at the interface exceeds the mobilized bearing capacity of the subgrade. The mobilized bearing capacity of the subgrade depends on the undrained shear strength of the subgrade, the surface deformation or rut depth, the tire contact area, and the base thickness.

The presence of a properly selected geosynthetic at the base/subgrade interface results in a stabilization effect, which decreases subgrade deformation and allows for a higher bearing capacity factor than if there was no geosynthetic. Giroud and Noiray (1981) suggested bearing capacity factors of 3.14 and 5.14 in the

case of unreinforced and geotextile-reinforced unpaved roads, respectively. These bearing capacity factors have been adopted in the G-H method. In the case of a geogrid-reinforced base, the lateral restraint due to geogrid-aggregate interlock results in an inward shear stress on the subgrade, which increases the bearing capacity factor from 5.14 to 5.71, as shown by Giroud and Han (2004a).

Based on all of the above considerations, Equation 1 (Table 1) for estimating the required base thickness was developed by Giroud and Han (2004a). The notations are in Table 2. The base thickness determined by the G-H method is a compacted base thickness rather than an initial, uncompacted base thickness.

It is important to note that Equation 1 is generic, because it has been developed without assuming the use of any specific geosynthetic. As a result, it can be used for unreinforced, unpaved roads and for unpaved roads reinforced with any type of geosynthetic. The selection of the values of the parameters α_0 , ξ , ω , n , and k is discussed below.

Selection of some parameter values

The values of four of the five parameters mentioned above, α_0 , ξ , ω , and n , can be selected without making any assumption on the type of geosynthetic. The selection of the values of these parameters is discussed below. The selection of the value of the fifth parameter, k , which depends on the geosynthetic, will be discussed in the following section.

Giroud and Han (2004a) interpreted the results of cyclic plate loading tests on unreinforced, unpaved roads and geogrid-reinforced unpaved roads performed by Gabr (2001) and concluded that α_0 can be considered constant for all unpaved roads constructed with unbound aggregate, unreinforced or reinforced, and that the value of 1/1.26 could be used for $\tan \alpha_0$ in all cases.

The three unknown parameters, ξ , ω , and n , were determined by Giroud and Han (2004b) using field data for unpaved roads constructed with unreinforced, unbound aggregate published by Hammitt (1970). The following values of these three parameters were found to provide the highest correlation between the measured base thickness values and the values calculated using Equation 1: $\xi = 0.9$, $\omega = 1.0$, and $n = 2.0$.

Using the above numerical values for $\tan \alpha_0$, ξ , ω , and n , Equation 1 becomes Equation 2 (Table 1). It should be noted that the above numerical values for $\tan \alpha_0$, ξ , ω , and n , are not necessarily set forever. It is possible that new test data will lead to different values for some or all of these four parameters. However, the authors of the G-H method believe that Equation 2 can be safely used in the meantime. Therefore, Equation 2 was used in the original papers (Giroud and Han, 2004a, b) for the next step, which is the calibration of k .

As with Equation 1, Equation 2 is generic because the four parameters (α_0 , ξ , ω , and n) were calibrated independently of any reinforcement material. So Equation 2 is applicable to all cases: unreinforced unpaved roads, geotextile-reinforced unpaved roads, and geogrid-reinforced unpaved roads (all constructed with unbound aggregate). The only parameter that needs calibration before Equation 2 is used to design a reinforced unpaved road is the dimensionless parameter k , which depends on radius of tire contact area, base thickness, and reinforcement. Calibration of the G-H method through the dimensionless parameter k is discussed in the following section.

Calibration and validation of the Giroud-Han method

Because Equation 2 contains an unknown parameter, k , it must be calibrated. Since k represents the effect of the rate of deterioration, calibration should be done using tests that model the behavior of the unpaved road base under repeated loads. Furthermore, calibration should be done using relevant properties. Therefore, calibration should be done using a property (or a set of properties) of the geosynthetic shown to correlate with the performance of an unpaved road reinforced with that specific geosynthetic.

Giroud and Han (2004a) found that, for a geogrid-reinforced unpaved road, the deterioration rate correlated with the aperture stability moduli of the specific geogrids considered in their study*. They established the following relationship based on an interpretation of laboratory cyclic plate loading tests on geogrid-reinforced unpaved roads by Gabr (2001):

$$k = \tan \alpha_0 (0.96 - 1.46J^2) \left(\frac{r}{h} \right)^{1.5} = 1.26 (0.96 - 1.46J^2) \left(\frac{r}{h} \right)^{1.5} \quad (3)$$

where J = aperture stability modulus of geogrid (with $J = 0$ for unreinforced and geotextile-reinforced unpaved roads). Measurement of the aperture stability modulus is presented in a draft test method by Kinney (2000).

*Tensor biaxial geogrids, BX1100 and BX1200

TABLE 1 Equations written with c_u for the shear strength of the subgrade

Basic generic equation:

$$h = \frac{1 + k \log N}{\tan \alpha_0 [1 + 0.204(R_E - 1)]} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - \xi \exp \left(-\omega \left(\frac{r}{h} \right)^n \right) \right] N_c c_u}} - 1 \right] r \quad (1)$$

Generic equation derived from Equation 1 with numerical values of ξ , ω and n

$$h = \frac{1.26(1 + k \log N)}{1 + 0.204(R_E - 1)} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - 0.9 \exp \left(-\left(\frac{r}{h} \right)^2 \right) \right] N_c c_u}} - 1 \right] r \quad (2)$$

Equation calibrated for specific biaxial geogrids* but not validated by field tests:

$$h = \frac{1.26 + (0.96 - 1.46 J^2) \left(\frac{r}{h} \right)^{1.5} \log N}{1 + 0.204(R_E - 1)} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - 0.9 \exp \left(-\left(\frac{r}{h} \right)^2 \right) \right] N_c c_u}} - 1 \right] r \quad (4)$$

Equation calibrated for specific biaxial geogrids* and validated by field tests:

$$h = \frac{0.868 + (0.661 - 1.006 J^2) \left(\frac{r}{h} \right)^{1.5} \log N}{1 + 0.204[R_E - 1]} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - 0.9 \exp \left(-\left(\frac{r}{h} \right)^2 \right) \right] N_c c_u}} - 1 \right] r \quad (5)$$

See notations in Table 2

Equation 3 is applicable only to two specific biaxial geogrids*.

Combining Equations 2 and 3 gives Equation 4 (Table 1). Since Equation 4 results from calibration done using laboratory tests, Giroud and Han (2004a, b) found it necessary to validate this equation using field data. Values of the base thickness h calculated with Equation 4 were then compared to values of the base thickness obtained in the field by Hammitt (1970) for the same number of axle passes for unreinforced unpaved roads. An average ratio of 0.689 was found between base thickness values observed in the field and calculated, hence Equation 5 (Table 1) is obtained by multiplying Equation 4 by 0.689.

Equation 5 is applicable only to the two biaxial geogrids used for this calibration*. However, an equation such as Equation 5 can be obtained for any type of geosynthetic by calibrating and validating Equation 2 for the considered geosynthetic.

The process includes four steps:

- 1) selecting a relevant property (or several relevant properties) of the considered geosynthetic—i.e., one or several properties (not necessarily J) likely to give good correlation with the performance of an unpaved road incorporating that geosynthetic.
- 2) obtaining an expression for k similar to Equation 3, but where J is replaced by the selected property (or properties).
- 3) obtaining an equation similar to Equation 4, by combining Equation 2 with the expression obtained for k in the preceding step.
- 4) deriving an equation similar to Equation 5 by validating Equation 4 using field tests.

It is possible, however, to conceive a one-step calibration/validation process where the parameter k in Equation 2 would be calibrated using field tests that would simultaneously provide validation, which would lead directly to an equation similar to Equation 5.

Discussion of the calibration and validation

Equation 4 incorporates only the aperture stability modulus to model the effect of two specific biaxial geogrids* on aggregate thickness reduction, because this parameter had been shown in the original publication (Giroud and Han, 2004a) to correlate by itself with the performance of unpaved roads reinforced with these biaxial geogrids.

This was shown using geosynthetic-specific performance testing, which led to Equation 3—i.e., a relationship between the aperture stability modulus, J , of these geogrids and the performance of reinforced aggregate bases. Other commonly referenced properties of these geogrids, in particular ultimate tensile strength, have not been shown to correlate with road performance and, therefore, are not appropriate properties to calibrate the G-H method for two specific biaxial geogrids*.

Furthermore, other studies have also shown good correlation between road performance and the aperture stability moduli of these two specific geogrids* and a few other geogrids that were available at the time of the studies. For example, Webster (1992) and Collin et al. (1996) found that the aperture stability moduli of the geogrids included in their studies gave good correlation with the measured performance of paved roads incorporating these geogrids.

The above discussion shows that there are good reasons to use the aperture stability modulus to calibrate the G-H method for the two specific biaxial geogrids*. However, this does not mean that J is the only meaningful property of the specific biaxial geogrids evaluated, but it is a measurable property for which a mathematical relationship to performance can be established. In reality, it is likely that all of the properties (aperture size, rib geometry, tensile properties) work together and combine to deliver the observed performance. A sensitivity study may be conducted to investigate the importance and influence of each property; however, such a study may be extensive, time-consuming, and costly.

While the aperture stability modulus has been shown to be an appropriate property to calibrate the G-H method for specific types of geogrids*, it should not be considered a universal indicator of performance for all forms of geogrid. Therefore, the G-H design method does not have to be used with the aperture stability modulus if another relevant property can be identified for a particular geosynthetic. In other words, the aperture stability modulus may not be an appropriate property to correlate with the performance of unpaved roads incorporating geogrids other than the two biaxial geogrids* that were used as an example in the original papers by Giroud and Han (2004a, b).

Based on the above discussions, the G-H method must be calibrated for each specific geosynthetic, and the calibration should be complemented by validation using full-scale tests.

Tests used for calibration must be as representative as possible of actual field conditions. Calibration of the method for a specific geosynthetic should be done using full-scale moving wheel tests or large-scale cyclic plate-loading tests.

*Tensar biaxial geogrids, BX1100 and BX1200

TABLE 2 Notations used in equations

h	= required base thickness, as measured after compaction
N	= number of axle passes
k	= dimensionless parameter depending on base thickness and reinforcement, which should be calibrated
α_o	= basic stress distribution angle for one load application on a homogeneous soil with no reinforcement
R_E	= limited modulus ratio of base to subgrade soil (i.e., ratio of the base modulus to the subgrade modulus, or 5, whichever is less, for the reason explained by Giroud and Han, 2004a)
P	= wheel load
r	= radius of equivalent tire contact area
s	= allowable rut depth
f_s	= reference rut depth, equal to 75 mm if s is in millimeters and 3 in. if s is in inches
c_u	= undrained shear strength (cohesion) of the subgrade
N_c	= bearing capacity factor, with $N_c = 3.14$ for unpaved roads constructed of unreinforced aggregate, $N_c = 5.14$ for geotextile-reinforced unpaved roads, and $N_c = 5.71$ for geogrid-reinforced unpaved roads
ξ , ω and n	= unknown parameters, calibrated using field data for unpaved roads constructed with unreinforced, unbound aggregate published by Hammitt (1970)

Small-scale tests may be used to study how variations of properties within a given geosynthetic "family" influence performance of that family, but they cannot and should not be used for validation. Validation should be done only with full-scale experiments or test installations. Documented case histories can provide valuable information that complements the data from full-scale tests, thereby contributing to the validation of the method for a specific geosynthetic.

Calibration and validation of the design method for newly introduced geogrids with triangular apertures followed this procedure (i.e., the data from full-scale moving wheel tests and large-scale cyclic plate-loading tests were used). This procedure should be followed for every geosynthetic intended to be used in unpaved road applications. Even if a new geosynthetic has index properties similar to those of a geosynthetic for which the G-H method has been calibrated and validated through full-scale tests, it is important to implement the calibration and validation procedures for this new geosynthetic.

Expression of the G-H method as a function of the CBR

The undrained shear strength of the subgrade, c_u , plays a key role in Equations 1, 2, 4, and 5 (Table 1). In practice, the undrained shear strength of the subgrade is often expressed in terms of California Bearing Ratio (CBR). If CBR is used, it is important to establish a relationship between undrained shear strength and CBR. The following relationship has been suggested to estimate the undrained shear

strength of the subgrade as a function of the subgrade CBR (Giroud and Noiray, 1981; Giroud and Han, 2004a):

$$c_u = f_c \text{ CBRsg} \quad (6)$$

where: c_u = undrained shear strength (cohesion) of the subgrade soil (kPa); CBRsg = CBR of the subgrade soil; and f_c = factor (kPa).

The value $f_c = 30$ kPa proposed by Giroud and Noiray (1981) for fine-grained soils (silt and clay) has been adopted by Giroud and Han (2004a). The f_c value may be different if the soil is not saturated and/or is not a fine-grained soil. Qian (2009) reported an f_c value of 20.5 for a clayey sand. However, Gregory and Cross (2007) suggested an f_c value of 11.1 for a cohesive soil, which is significantly lower than values suggested by others. The relationship between c_u and CBRsg should be verified or established if CBRsg is used in design.

In Equations 1, 2, 4, and 5, c_u can be replaced by its expression given by Equation 6. Combining Equations 1 and 6 gives Equation 7 (Table 3), which is generic as is Equation 1.

Combining Equations 2 and 6 gives Equation 8 (Table 3), which is identical to Equation 7, but where the parameters α_0 , ξ , ω , and n have been replaced by their best numerical value currently available.

Combining Equations 5 and 6 gives Equation 9 (Table 3) for the design of unpaved roads incorporating specific biaxial geogrids*.

Applicability and limitations

Giroud and Han (2004a, b) stated that the G-H design method is applicable and limited to the following conditions:

1) The subgrade soil is assumed to be saturated and to have a low permeability (silt, clay). Therefore, under traffic loading, the subgrade soil behaves in an undrained manner. Practically, this means that the subgrade soil is incompressible and frictionless. For example, this requirement excludes unpaved roads built on peat.

2) The G-H method as initially published had been verified for rut depth between 50 and 100 mm. However, through extensive use of the method, it has been determined that the method is applicable to rut depths as small as 40 mm. Therefore, the validity of the method is currently limited to rut depths ranging between 40 and 100 mm. More calibration work, based on more field data, would be required to extend the validity of the method to a broader range of rut depths. These rut depths, essentially due to the deformation of the subgrade, are measured at the surface of the aggregate base. These are different from surface ruts, which may form during the construction process due to surficial disturbances of the base materials and not because of subgrade deformation. These surface ruts should be filled, rather than graded, prior to proof rolling to maintain the required base or subbase thickness above the geosynthetic.

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3) The minimum required thickness of the base is 100 mm because the base thicknesses used in the calibration were no less than 100 mm and because such thickness is necessary for constructability. The base thickness determined by the G-H method is a compacted base thickness rather than an initial, uncompacted base thickness. To properly use the G-H method, the base thickness considered in design and in calculations done to compare different solutions should always be the compacted base thickness.

The above limitations are related to the generic aspects of the G-H method. Also, Equations 4, 5, and 9 are applicable to only two

specific biaxial geogrids* and should not be used for any other geosynthetic. For other geosynthetics, calibration and validation of Equation 2 should be done as described above.

All of the above equations that give the required base thickness, h , must be solved by iterations because the term h is on both sides of the equation.

TABLE 3 Equations written with CBR_{sg} for the shear strength of the subgrade

(These equations were derived from Equations 1, 2, and 5, respectively, using Equation 6.)

Basic generic equation equivalent to Equation 1:

$$h = \frac{1 + k \log N}{\tan \alpha_0 [1 + 0.204(R_E - 1)]} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - \xi \exp\left(-\omega \left(\frac{r}{h}\right)^n\right)\right] N_c f_c CBR_{sg}}} - 1 \right] r \quad (7)$$

Generic equation (equivalent to Equation 2), derived from Equation 7 with numerical values of ξ , ω and n

$$h = \frac{1.26(1 + k \log N)}{1 + 0.204(R_E - 1)} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - 0.9 \exp\left(-\left(\frac{r}{h}\right)^2\right)\right] N_c f_c CBR_{sg}}} - 1 \right] r \quad (8)$$

Equation (equivalent to Equation 5) calibrated for specific biaxial geogrids* and validated by field tests:

$$h = \frac{0.868 + (0.661 - 1.006J^2) \left(\frac{r}{h}\right)^{1.5} \log N}{1 + 0.204[R_E - 1]} \left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_s}\right) \left[1 - 0.9 \exp\left(-\left(\frac{r}{h}\right)^2\right)\right] N_c f_c CBR_{sg}}} - 1 \right] r \quad (9)$$

See notations in Table 2

*Tensor biaxial geogrids, BX1100 and BX1200

Conclusions

The basic equation developed by Giroud and Han (2004a, b) for the required thickness of unreinforced and/or geosynthetic-reinforced bases is generic. Therefore, this equation can be used for unpaved roads reinforced with any type of geosynthetic, provided it is calibrated for the specific type of geosynthetic considered.

This article has discussed the calibration of the Giroud-Han (G-H) method in detail. In particular, it has been indicated that the aperture stability modulus, which is an appropriate property to calibrate the G-H method for some specific biaxial geogrids*, may not be appropriate for other types of geogrids.

Geosynthetic index tests of physical or mechanical properties are not univer-

sal indicators of the performance of unpaved roads, and higher-strength geosynthetics do not necessarily perform better in unpaved road applications. Physical or mechanical properties that are important for one form, type, or family of geosynthetics may not apply to other forms, types, or families of geosynthetics. If several geosynthetics appear to be similar, the method must be calibrated for each one. Furthermore, the applicability of the method for each of these geosynthetics must be validated using full-scale tests.

Calibration based only on small-scale tests and the index properties of the geosynthetic could lead to a false sense of security that the unpaved road design will meet performance expectations. Based on the limitations of the G-H method, as presented in this article, the designer should always verify that geosynthetic-specific full-scale testing along with case histories, for which a calibrated and validated G-H equation was utilized, resulted in satisfactory performance of the constructed unpaved road.

Issues have arisen as a result of the widespread use of the method. Issues related to the development of the G-H method were addressed in this article. Issues related to the use of the method are addressed in Part 2 in the April/May 2012 issue of *Geosynthetics*.

*Tensor biaxial geogrids, BX1100 and BX1200



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