I am very honoured to be awarded a 2004 IGS Award. This IGS Award was given for contributions to the development of techniques to improve the seismic stability of geosynthetic-reinforced bridge piers using novel systems of preloading and prestressing. These techniques hold great promise to reduce deformations of reinforced piers under traffic loading and during earthquakes. The work has been validated by both full-scale field structures and laboratory model tests using a shaking table.

The preloading and prestressing (PLPS) procedure was originally developed to substantially decrease the residual settlement at the top of backfill subjected to long-term live loads such as traffic loads. Furthermore, a novel aseismic system of the preloaded-prestressed reinforced soil method was proposed and validated. Using this method, it is now possible to construct reliable and critical civil engineering structures such as geosynthetic-reinforced soil structures (i.e., bridge abutments and bridge piers).

In this procedure, a sufficiently large vertical preload is applied to the reinforced backfill by introducing tension into metallic tie rods that penetrate the reinforced backfill with the ends fixed to the bottom and top reaction blocks (Figure 1). In addition, the stiffness and strength of the backfill, while the structure is in service, is always kept sufficiently high by maintaining sufficiently high prestress. By this preloading and prestressing construction procedure, the transient deformation of reinforced backfill subjected to traffic loads could become very small and essentially elastic and, thereby, the long-term residual deformation could become minimal.

In the summer of 1996, the first prototype preloaded and prestressed geosynthetic-reinforced soil (GRS) bridge pier was constructed to support two railway bridge girders in Fukuoka City, Japan. The pier was 2.7 m high and the backfill was well-compacted, well-graded crushed gravel that was reinforced with geogrid layers with an average vertical spacing of 15 cm. The residual settlement of the pier after approximately 120 train passings/day from the beginning of August 1997 (train service started) to the end of March 2001
(end of train service) was very small. The train usually consisted of two coaches, each weighing about 350 kN without passengers.

Long-term measurements of the tie rod tension and the compression of the pier backfill was started immediately before applying the preload on 5 September 1996. The maximum transient compression of the backfill caused by each train passing was only approximately 0.025 mm and was measured using a pair of sensitive displacement transducers. This minimal amount of compression translates to a vertical strain in the backfill of as little as 0.001%.

It is important to note that the deformation of gravel (and sand) is essentially elastic, when the strain is smaller than this order of strain amplitude. Therefore, for superior performance of PLPS reinforced soil structures, it is critical to keep the transient strain in the backfill as small as 0.001% by attaining a high backfill stiffness.

When a PLPS reinforced soil structure such as the one described above is slender and the initial prestress is too low, the structure may exhibit large bending deformations when subjected to high-level seismic loads (Figure 2a). In this case, the height of the backfill at both sides of the PLPS reinforced soil structure may significantly increase and decrease cyclically.

When the height of the backfill increases significantly, the vertical stresses in the backfill zone may become temporarily very low or approximately zero. Then, the shear strength and stiffness of the backfill zone may become very low, resulting in excessive shear deformation of the backfill. For this reason, it is necessary to keep the bending deformation of the PLPS reinforced backfill structure sufficiently small during seismic loading by using particular measures (Figure 2b).

A newly developed aseismic system called a 'ratchet system' was originally proposed, which has the following two functions. First, when the backfill exhibits vertical compression, such as creep deformation and transient and residual compression by shaking-induced shear and bending deformation, the ratchet system is unlocked while a relatively long and relatively soft spring that is attached between the top end of each tie rod and the top reaction platen extends according to the vertical compression of the backfill (Figure
3b). In this way, the stiffness of each tie rod system becomes very low while the prestress level is kept high and close to the initial level.

Second, when the backfill exhibits dilatancy or expansion, or both, by backfill bending deformation, the ratchet system is locked, which makes the stiffness of the tie rod system very high, exerting the original stiffness of the tie rods (Figure 3c). In this way, the tie rod tension increases largely in response to the trend of increasing backfill height. These two functions of the ratchet system described above effectively restrain large bending deformations as well as large shear deformations of the backfill.

Figure 3. Two different functions of the ratchet connection for tie rods.

A series of laboratory model shaking table tests were performed to evaluate the improvement of the dynamic performance of mechanically reinforced soil structures that are vertically preloaded and prestressed by using a ratchet connection for the tie rods. For relatively slender reinforced backfill structures, the maintenance of high prestress is particularly important to restrain the occurrence of large backfill bending deformation. For these purposes, it is proposed to fix the top end of the tie rods to the crest of the structure by using a ratchet connection, which allows free compression of the backfill at nearly constant prestress, while mechanically not allowing any expansion of the backfill.

To avoid a resonant or near-resonant state during seismic loading, it is suggested that the initial natural frequency value of a given structure be designed sufficiently higher than the anticipated predominant frequency of the given seismic load while the natural frequency during dynamic loading is maintained higher than the anticipated predominant frequency using a ratchet connection.

I have many people to thank. I had the opportunity to work for one year with Prof. Bathurst and his colleagues at the Royal Military College of Canada after successfully defending my Ph.D thesis. Their many and significant contributions to the development of reinforced soil structures has incited me to further my research efforts. I would like to thank Prof. Bathurst for making this opportunity possible.

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