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New Materials for Tunnel Supports

Nouveaux matériaux pour le soutènement de tunnels

Neue Materialien im Tunnelausbau

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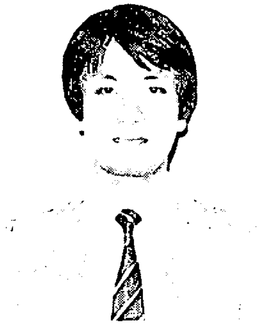

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SUMMARY
For the purpose of improving the durability and work productivity of tunnel supports, the non-corrosive, light-weight new material fiber reinforced plastics formed in grid shapes to replace steel bars has been applied for shotcrete and concrete lining. Furthermore fiber reinforced plastics rock bolt has been resently developed.

RÉSUMÉ
Le matériau plastique armé de fibres -un nouveau matériau non corrosif et léger fabriqué en treillis et destiné à remplacer les barres d'aciers -a été développé dans le but d'améliorer la durabilité et la productivité dans les soutènements de tunnel. Ce matériau est mis en application dans les soutènements en béton projeté et en béton de revétêment. On a aussi développé des aucrages dans la roche en matériau plastique armé de fibres.

ZUSAMMENFASSUNG
Zur Verbesserung und Gleitschalungen von Lebensdauer und Arbeitsproduktivität im Tunnelausbau wurde für Spritzbeton das nichtrostende, leichte, Material FRP in Gitterform als Ersatz für Stahlbewehrung verwendet. Außerdem wurden Felsanker aus FRP entwickelt.

1. INTRODUCTION

Recently in Japan, the New Austrian Tunnelling Method (NATM) has rapidly become popular according as the progress of rock mechanics. The tunnel supports in NATM are mainly composed of shotcrete, rock bolts and concrete lining. Welded wire fabrics or steel bars are often used for reinforcing shotcrete or concrete lining. However, these materials including rock bolts are made of steel, therefore the durability of the tunnel supports attacked by ground water or flowing water is not reliable, and the work productivity is low due to their heavy weight.

On the other hand, the newly developed New Fiber Composite Material for Reinforcing Concrete (NEFMAC) to replace steel bars, which is made of fiber reinforced plastics (FRP), is non-corrosive and light in weight, therefore it is well suited for the reinforcing materials for shotcrete or concrete lining. Another newly developed FRP rock bolt has enough tensile and bond strength, and it is easy for handling. The characteristics and applications of these materials for tunnel supports are described in this paper.

2. CHARACTERISTICS OF NEFMAC

Table 1 Characteristics of NEFMAC

Characteristic	Effect
• Non-corrosive	• Improving the durability of concrete structure under severe condition
• Using continuous fibers	• Effective use of fibers
• Enough strength at the cross points	• Sufficient anchorage to concrete • Lapped splice joint
• Light in weight (specific gravity ≒ 2) • Forming in complicated shapes	• Improving work productivity in the field

NEFMAC is a new composite material for reinforcing concrete, which is made of high strength continuous glass and/or carbon fibers impregnated with resin and formed in grid shapes by the filament winding method [1]. Its characteristics are shown in Table 1. Fig. 1 shows the load - strain relationships of deformed steel bar ϕ10mm (Grade 50), NEFMAC G10 (glass fiber) and H10 (glass and carbon fiber).

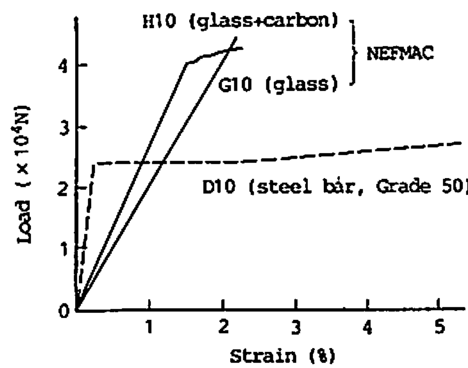

Fig. 1 Load-strain relationship of NEFMAC and deformed steel bar

3. APPLICATION FOR REINFORCING GRIDS FOR SHOTCRETE

3.1 Function and Setting Method of Reinforcing Grids

The purpose of reinforcing grids is to improve the rebound ratio and ductility of shotcrete and to prevent it from falling off. Generally they are set between the primary and secondary layers of shotcrete to exhibit their function. The easy, speedy and continuous setting method of NEFMAC on the surface of the primary shotcrete with quenched staples using compressed-air gun has newly been developed. This new setting method of NEFMAC is shown in Fig. 2.

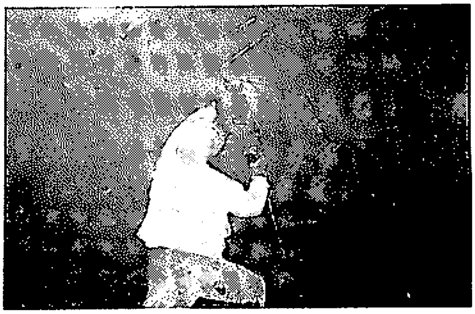

Fig. 2 Setting method of reinforcing grids for shotcrete

3.2 Clearance between Reinforcing Grids and Surface of Primary Shotcrete

Fig. 3 shows the average clearance between each reinforcing grids and the surface of the primary shotcrete. The averages and deviations of the clearance become smaller as the stiffness of reinforcing grids becomes lower. From this result, NEFMAC can curtail the amount of the secondary shotcrete as much as the difference of the clearance between NEFMAC and welded wire fabrics when they secure the same cover from the surface of the secondary shotcrete.

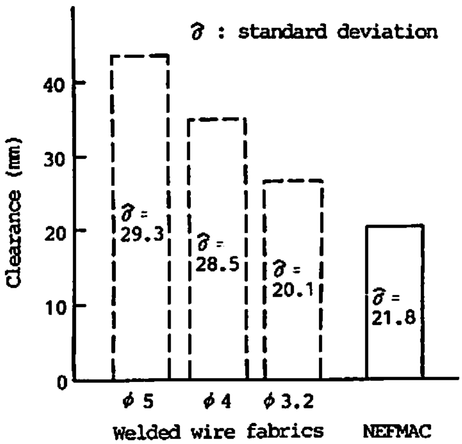

Fig. 3 Clearance between reinforcing grids and surface of primary shotcrete

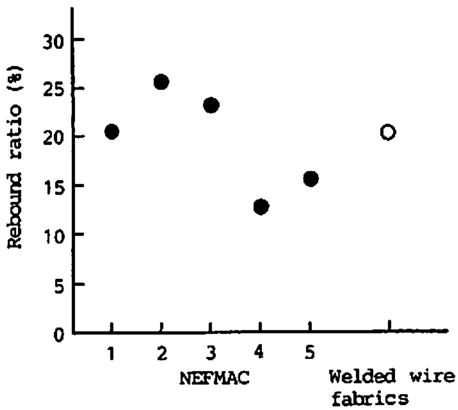

Fig. 4 Rebound ratio of shotcrete

3.3 Rebound Ratio of Shotcrete

The rebound ratio of the secondary shotcrete with NEFMAC is almost the same as that with welded wire fabrics (See Fig. 4).

3.4 Work Productivity and Economy

The new setting method of NEFMAC with staples is more efficient than the ordinary ones of welded wire fabrics, so the setting rate became 1.7 to 5 times higher. Furthermore, the amount and time of the secondary shotcrete decreased. Then the cycle time decreased. For the above reasons, this method has also a merit in economy.

4. APPLICATION FOR REINFORCEMENTS FOR CONCRETE LINING

4.1 Reinforcements for Invert and Arch

Since NEFMAC can be formed in curved shape as well as flat one, and is light in weight, it was adopted as reinforcements for concrete lining of a water-conveyance tunnel in order to greatly improve work productivity. The reinforcements for invert and arch were formed separately in longitudinal and circumferential directions for the sake of transportation and setting in the tunnel. Since NEFMAC has enough strength at the cross points, it was set with lapped splice joints. The reinforcements for invert and arch are shown in Fig. 5 and Fig. 6 respectively.

Fig. 5 Reinforcements for invert of concrete lining

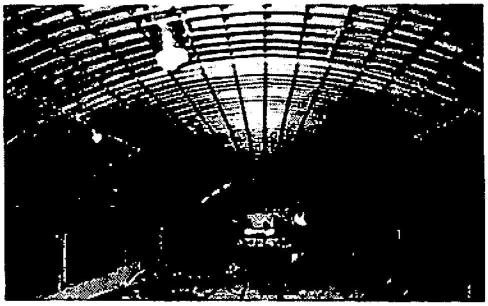

Fig. 6 Reinforcements for arch of concrete lining

4.2 Work Productivity

NEFMAC was transported into the tunnel in pre-assembled form, therefore the assembling time became about one third shorter than that of steel bars. Furthermore, NEFMAC is light in weight and easy to be set without expert workers.

5. FRP ROCK BOLT

5.1 Characteristics

In general, FRP rock bolt has enough durability and it is much lighter in weight than steel one, furthermore it is easy to be cut and removed when the surrounding rock is excavated. However, ordinary FRP rock bolt is only effective as temporary support but not as permanent one because of its small head strength. Therefore, the new FRP rock bolt which has a special type of head has been developed, so its tensile strength is equal to or greater than that of steel one. And on its surface, continuous fibers impregnated with resin are wound spirally to improve bond property.

5.2 Head Displacement and Bond Property

Fig. 7 shows the pull load-head displacement relationship of the steel rock bolt (ϕ25mm, L=2.5m) and the equivalent FRP one at the pull test in a tunnel. FRP rock bolt has large displacement but enough tensile strength, so it can be used as permanent support. Fig. 8 shows the distribution of longitudinal and bond forces of two kinds of rock bolts. Most of bond force on the steel rock bolt occurs near the rock surface, but that on FRP rock bolt becomes larger inside in accordance with the increase in the pull load. From these results, FRP rock bolt has small stiffness, it will be more effective for soft or swelling rock than hard one.

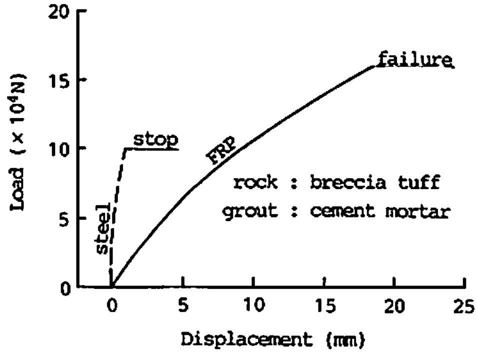

Fig. 7 Pull load-head displacement relationship of rock bolt

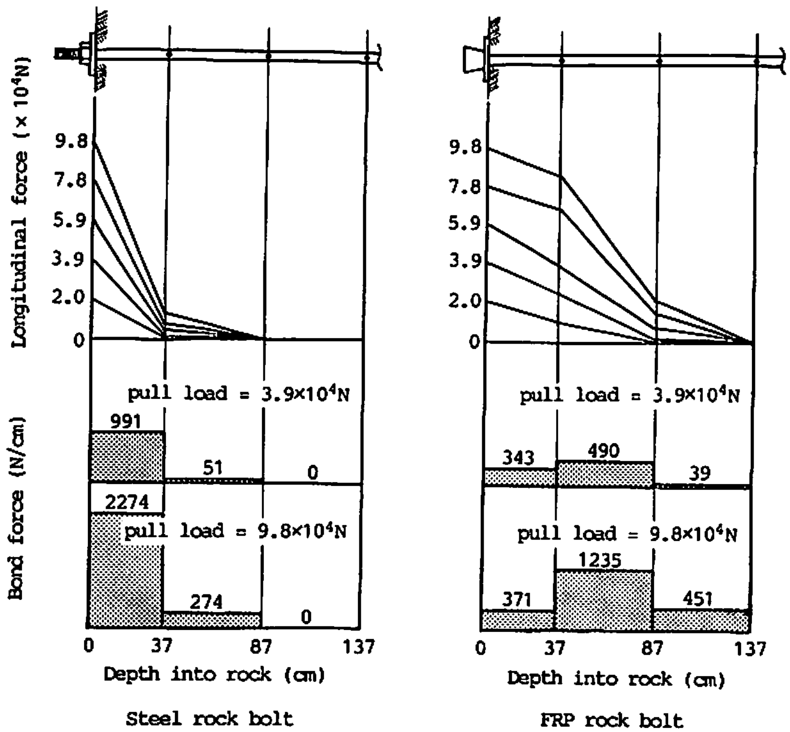

Fig. 8 Distribution of longitudinal and bond force of rock bolt

6. CONCLUDING REMARKS

NEFMAC has already been used as reinforcing grids for shotcrete at several tunnels in Japan. It was also used at an advancing drift because it is easy to be excavated after setting. In the near future, it will be used at large underground rock caverns such as electric power plants or petroleum storage. On the other hand, there are only a few application cases of NEFMAC as reinforcements for concrete lining, but it is best suited for repairing tunnels under severe conditions and reducing the term of works. FRP rock bolt can be used as permanent support and it will be effective for soft or swelling rock.

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