Handbook of Roadpower-2006 FRP Rockbolt

CHAPER One Introduction of OCEANPOWER engineering technology CO., LTD

OCEANPOWER engineering technology CO., LTD is a subsidiary company of OCEANPOWER CORPORATION.

The main business is related to the investigation of new materials and industrialization of new technology.

We have 56 subsidiary companies and branches in the Chinese Mainland, Europe, USA, Hong Kong and Macao;

We are a high-tech private-owned company that holds several patents in our business fields. Oceanpower is the representative company for the Chinese government for several national and industrial standards.

OCEANPOWER engineering technology product assortment includes following engineering materials:

- ✧ PAN fiber for asphalt ----Delannite AS fiber
- ✧ Road power colorful asphalt concrete
- ✧ Road power-2008 kevlar sheet
- ✧ Road power-2002 PAN cement fiber
- ✧ Road power-2002 FRP rockbolt

OCEANPOWER engineering technology has high technical experience and the latest industrial technology. We can provide technical services for engineering design and construction to our clients. All our products have been applied in hundreds of important projects all around China, so OCEANPOWER engineering technology has successfully promoted the development of modern materials and it’s spreading in the China.

Chapter Two introduction of Road power-2006 FRP rockbolt

Road power-2006 FRP rockbolt is a kind of advanced composite material. From cooperation of several professional organizations, Oceanpower finally gained the manufacturing process of FRP rockbolt. This product has been applied and used in the reinforcement of tunnels, slopes and mines.

1、Characteristic of FRP material

The main material used in the production of FRP (fiber reinforced polymer) rockbolt is synthetic resin and composite fiber; which is a kind of binder. The composite fiber is made of reinforced substance. FRP rockbolt that is made by applying pultrude techniques has many advantages, for example:

The ratio of the relative density is 1.8 ~ 2.1 and the tensile strength is more than 50Mpa. The maximum tensile stress is 15t for Φ20 mm (the relative density ratio of steel is 7.8, the tensile strength is 335 ~ 400 Mpa), from this it can be concluded that FRP could actually replace the reinforcing steel bar. When a FRP material is cut there will be no sparkle formation and it will also prevent corrosion. Therefore this material has been widely applied in tunnel- and mine-construction in US、Germany、UK、France etc.

The extensibility of FRP material is relative small when a part of the rod breaks. The reinforced fiber will then split in sections, and the composite fiber will still keep the connection to the main body. The shear strength of FRP rockbolt is above 70KN. If a resin anchor agent is added then the straight will be even higher. Road power FRP rockbolt can fit in with the need of antistating.

2、Technical parameter for road power 2006 FRP rockbolt

2.1 Appearance

The structure of the FRP rockbolt spirally formed, with symmetric shape.

2.2 Dimensional deviation

length variation: ± 10mm

diameter deviation: ± 1mm

non-straightness of body: ⩽ 3mm/m

the length of tail thread: ⩾ 100mm

2.3 Technical parameter (solid)

Technical parameters of Road power –2006 FRP rockbolt **Table 1**

Item	Diameter (mm)	Weight （kg/m）	Tensile strength (MPa)	Shear strength (MPa)	Torque moment (N · m)	the bearing of tail thread（KN）
FRP-16	16	0.394	≥500	≥110	≥60	≥50
FRP-18	18	0.497				
FRP-20	20	0.615				
FRP-22	22	0.745				
FRP-25	25	0.961				

note: the diameter of rockbolt is between Φ16 and Φ32.

2.4 The performance of antistatic and anti-flaming

Meet to the request to MT113-1995 (mine) in China.

3、The Characteristics of Road power –2006 FRP rockbolt

- ✧ Advanced manufacturing technique;
- ✧ Uniform body strength;
- ✧ Very high tensile strength;
- ✧ Antistatic and anti-flaming;
- ✧ Steady thermal expansion coefficient;
- ✧ Convenient installation;
- ✧ Very high durability;
- ✧ Light weight, density ratio is 1.96

4、Application areas of FRP rockbolt

4.1 Application

FIP (FIB) has been investigating 35 steel rockbolt rupture examples. The amount of fractures in permanent rockbolt is 69% and in temporary rockbolt is 31%. However, half of rockbolt will crack or cankered within 2 years or later. At present time civil engineering expert has starting to pay more attention to this problem, for example corrugated pipes or aggregate formation in the cement slurry. The effect will not be ideal and the lifetime may vary from case to case but is usually 50~70 years. This problem will be solved when the application of composite rockbolt has become a common engineering practice. The problem lies in that the

anticorrosion and the durability of the composites have to meet engineering requirements needed.

The application area can be found in mines, communication, metros, water conservancy, military etc. At the same time because the body of FRP may is easily cut, so FRP rockbolt is fit for mine tunnel support especially in subterranean engineering constructions that has been used for a long time.

4.2 Application area

Application			
	**Systematic rockbolting**		**Slope stabilization**
	**Tunnel Enlargement**		**Pilot tunnel**
	**Partial extraction**		**Face stabilization**

Three Introductions of special anchorage agent

1、Abstract

There are two kinds of anchorage agent: fast-hardening cement anchorage agent and resin anchorage agent. According to resent data, resin anchorage agent fits better when composite rockbolt is applied in tunnel and mine. The ultimate withdrawal resistance of the rockbolts, should depend on field tests, because there are several factors that may affect its performance. Hardness of the rock, diameter of the drilled hole, effective anchorage length, grouting agent, and construction method are examples of factors that may have influence. At present time there is no perfect design method for composite rockbolt, so current design withdrawal resistance of the rockbolt can only be used as a rough estimation, and it should be verified by field test, to ensure the reliability and security of when applied.

Resin anchorage agent: anchorage agent refers to the material that acts as adhesive or bond. Resin anchorage agent consists of two components: the resin mortar and curing agent. The two components are separately packed in a wrap. When mixed the two components will react quickly, and will bond the bolt and rock together. Anchorage agent of CK and K ranges is a newly developed, fast hardening anchorage agent that is based on commonly used intermediate hardening anchorage agent. The gel time of the resin anchorage agent is 20~60minutes; 3 minutes after the components had been mixed then its compressive strength has become 30Mpa, and 80Mpa after one day.

The Bolt can be quickly assembled: after curing, then the pallet should quickly be put in place; 5minutes later its anchoring strength is 40KN.

Main properties of resin anchorage agent (resin cartridge) table2

Property	Value	Property	Value
Compressive strength	≥60MPa	Vibration fatigue	>80,000times
Shear strength	≥35MPa	Poison ratio	≥0.3
Density	1.9~2.2g/cm^3	Shelf time	>9 months
Coefficient of elastic	≥1GPa	Applicable environment temperature	-30℃~+60℃

The resin anchorage is sorted according to its gel time and can be divided into four different types, which are: high speed (MSCKa, MSCK), high speed (MSK), intermediate speed(MSZ) and low speed(MSM).The Technical parameter are in table 2,3(the tests were done in a surrounding temperature of 22±1℃). Specifications of resin anchorage agent are in table 4. For the anchoring strength of different diameter and material, more tests needs to be done.

Product types of resin anchorage agent (resin cartridge) table 3

Type	Specialty	Gel time(s)	Stirring time(s)	Waiting time(s)	Color
CKa	Extra high speed	8~25	15	10~30	Yellow
CK		8~40		10~60	Red
K	High speed	41~90	25~40	90~180	Blue
Z	Intermediate speed	91~180	25~40	480	White
M	Low speed	>180	25~40		

Specifications of resin anchorage agent (resin cartridge) table 3

Type	Specification （mm）	Weight (g)	Diameter of drilled hole （mm）	Number in each box	Application area
3537	Φ35*370	700±10	Φ42±2	40	Well equipment assembly
3530	Φ35*300	550±10	Φ42±2	40	End anchorage of laneway rockbolt support in roadway
2835	Φ28*350	400±10	Φ32±2	40	Roadway rockbolt support in roadway and other
2850	Φ28*500	640±10	Φ32±2	40	Roadway support and full anchorage
2335	Φ23*350	300±10	Φ28±2	50	Roadway support of small diameters and full anchorage

2、Specification of roadpower resin anchorage agent

1、The resin anchorage agent that our company can supply: extra high speed (MSCKa, MSCK, high speed (MSK), intermediate speed (MSZ), low speed (MSM) for the following Diameters: Φ23、Φ28、Φ35 with different length according to the for clients.

2、Method for classification of the resin anchorage agent

MS：type、diameter：mm, length：cm, where M stands for rockbolt, S stands for resin anchorage agent. The type can be sorted as Ck extra high speed, high speed, Z intermediate speed, and M low speed.

For instance: MSCK2335 refers to an extra high-speed resin anchorage agent whose diameter is 23mm,length 350mm.

3、Application areas

(1) Full rock wells, coal roads, half coal roads, railways, highway tunnels, side slopes of dam, and foundation of bridge and slope pavements of side slopes in mines.

(2) Useable in shale, lime rock, sandstone, siltstone, mudstone. Cannot been

used in rock of badly water percolation and soft clay.

4、Executive standard of resin anchorage agent: MT146.12002

5、The length of anchorage agent should be determined by the properties of the rock supplied by clients, we could do design-anchoring strength and field test. When two or more anchorage agents are used to anchor the same rockbolt, the choice should be based on the curing speed of the anchorage agents so they have similar properties and can provide full-length anchorage.

6、The depth of the hole should be strictly controlled. The depth of the hole should in general be 60~80mm shorter than the length of rockbolt. The rockbolt cannot be used if the hole is too deep.

7、When the rockbolt hole is finished, high-pressured air should be used to blow away dust to fix the resin of the rockbolt.

8、According to design of the anchorage length, the end of anchor head should be used to send the anchorage agent to the bottom of the hole. When the head of anchorage agent contact the bottom, start the pug mill to stir the anchorage agent and at the same time press it to the bottom of the hole with uniform speed. Remember that the stirring time should be followed strictly.

9、When the stirring is finished, remove the pug mill, and then peg the bolt in time. It is forbidden to displace or sway the bolt within the hardening time, this is very important to remember when pallet is being fixed.

10、When anchorage agents of two different hardening speeds are used; the one with the higher speed should be put in the end of the hole.

11、Based on the field condition the right pug mill need to be chosen, such as hydraulic pressure bolt borer, pneumatic borer, electric borer and so on. It's more convenient to use the resin rockbolt borer or hydraulic pressure bolt borer for the low hardness rock when drilling and fixing resin rockbolt together.

12、Concerning the fixing device of resin rockbolt, we recommend that the specified speed of the device should be over 400 rounds/minute; Torque for full-length anchorage above 60NM, for end anchorage above 40NM.

13、The surface close to the anchorage agent should be cleaned with cloth or paper if tainted.

Notes: product storage and transportation

1、anchorage agent should be stored in a dry room below 25℃, not in strong sunlight and far away from fire.

2、If stored in 20~25℃ temperature. The guarantee period is more than three months from the production date. The product exceeding the guarantee period can also be used as long as it feels soft.

3、Anchorage agent should be packed in hard carton that is easily transported and impact resistant. Details can be found on the surface of the container.

4、When transported by railway, it can be transported either in a full container or together with other gods. Wet environment or direct sunlight should be avoided when transported by cars.

Four Introduction of rockbolt-support-related materials

1、Pallet

Steel plate, cast iron plate or polymer plate can be all used as pallet. Pallet is an important part of the rockbolt, even for the mortar rockbolt. Its mechanic properties it can directly affect the effect of the support. The principle of the pallet design is that the pallet's carrying capacity should comply with the rockbolt's to make sure the body of the rockbolt and the nut can be loaded equally.

2、Rockbolt nut

The Nut is an important accessory that fixes the support materials such as pallet, net, steel tape together. It plays an essential part in forming a support load and to control the deformation in roadways. Especially if a rockbolt lack of nuts, it can't support the rockbolt. Therefore, a correctly chosen rockbolt and nut can efficiently achieve the support. Considering the terms of usage, a siteration that sometimes occurs is that the nuts can't match the strength or the construction requirement. To solve this question, special round nuts and plastic damp nut has been developed.

3、Steel tape

Steel tape can connect the rockbolts with each other to compose uniform bearing condition and enhance the effect of rockbolt support. Steel tape is made from 2~3mm thin steel plate, with a hole in its center. According to the materials that make's the steel tape, it can be sorted by flat steel tape, plate steel tape, W steel tape and M steel tape.

4、Net

The usage of the net is to sustain the crushed rocks between rockbolts and prevent the rocks from falling off to increase the support effect. At present, there are different types and qualities, mainly including iron wire net, steel rebar net and plastic net. Iron wire net is commonly knitted with zinc coating iron wires, mainly including geographic net and diamond net. The dimension of mesh for diamond net is 40mm×40mm~100mm×100mm. For the reason of its high strength and convenient connections, the diamond net has been replacing the rectangular net.

Five Rockbolt support and construction technology

It is important to the support engineers to consider rockbolt support, anchoring-squirt support and assemblage support.

1、The request of construction

(1) The pattern with regard to the arrangement of the rockbolt in stretch-out view is in rectangles or diamonds.

(2) The rockbolts are vertical to the surface line of the roadway, In order apply the rockbolts, the rockbolts should be vertical to the laminar stratum. The workers should arrange the position of holes depending on the applying condition, for example the distance and array pitch (acceptable variation: 150mm). It is not permitted apply the rockbolt's if the inclined angle is less than 75°.

(3) The hole depth is according to the request operation condition. If the depth of the hole is less than design value then the basset will become too long. This will result in that the rockbolt can't reach the bottom of the hole and will reduce the support from the concentrated anchorage as well as the plate and stratum. The permitted variation of the depth of the hole is 50 mm for cement mortar rockbolt, for resin and quick-hardening cement rockbolt the permitted hole-depth is not less than the effective length of rockbolt and not more than 30mm and for friction rockbolt's the permitted hole-depth is 10 ~ 50 mm longer than the rockbolt.

(4) In order to ensure the quality of construction, the rockbolt hole must be cleaned from rock flour, fragment, water accumulation with air from a compressor.

(5) In order to ensure the enough anchoring strength, the worker must install the plate and the nut tightly so the relevant length of concentrated anchorage is about 200mm.

2、The construction technology of resin rockbolt

The worker ought to control the width and height with regard to the tunnel; in order to regulate the section, the rock roadway must apply the technology of blasting of profile. If the roadway is too wide and too high, then the worker must apply reinforcement methods. In order to ensure the quality of the construction, the temporary support used, must remain in the working area. It is forbidden to operate on the condition of the hollow plate.

The gel time of the anchorage agent of resin rockbolt is about 0.5 ~ 1.0min. The incensement of strength is very fast. The strength is about 21Mpa after 5min and after 30min the strength will be 65% ~ 90% of the final strength, which is about 60 ~ 120Mpa.The anchoring force is equal to 2.7 ~ 4.2 times compared with cement mortar and the anchoring force is close to 50KN within one day and the quality of production is steady. The workers should check the fittings of the rockbolt and resin packs to make sure that the resin anchorage

agents can be applied or not or not.

(1) The workers chose the specification of resin anchorage agents with regard to the diameter of hole.

(2) The workers should confirm the depth of the bore according to the requested design, the depth of bore should be 60 ~ 80mm shorter than the length of the rockbolt.

(3) The surface should be cleaned from dust by a compressor.

(4)According the design anchor length, the Road power-2006 FRP rockbolt should be inserted by a hand rotation or drilling machine, the rotation time should be about 30s±5s

(5)The workers should start with boarding up the opening with a spigot. The rockbolt should not be shaken before the resin cartridges have hardened. The installing part of the parietal eye is of great importance. The workers should test the anchoring force after 40min (middle speed) or 15 min (high speed) for the fast cartridge.

(6)The rockbolt can bear the installed plate after 7min (middle speed) or 15 min (high speed).

(7)According the driving condition in the area of application, you can use the TJ-9 rockbolt gas droved stirrer or an electric drill to drill a hole. The worker should tighten the nut with a gas driven QB-16 spanner or by a hand spanner. If the worker is using a rockbolt drill, It is more convenience to drill the hole and fixing the rockbolt with the same machine.

3、The construction of mortar rockbolt

The workers ought to ensure the capability of injecting material with regard to the rockbolt of cement mortar. Should use the above 425# metallic cement in order to ensure the mortar grade, the grain size of fine sand and medium sand is less than 2.5mm. The mixing proportion is 1:1 or 1:2 for cement and sand (weight ratio). The water-cement ratio is 0.38 ~ 0.45. In some situations we lacks of proper methods, because of limited of construction condition. For these cases the mixing proportion in the mix need to be prepared according to past experience. The operation norms are as following: make the mixture uniform; it should be mixed gradually after fresh water been added. The quality standard is that the mortar should be unable to loose, the water-cement ratio is 0.40 at this point. And the workers should fill the rockbolt hole with the cement mortar in one time.

4、《specification for bolt-shotcrete support》（GB50086-2001）

The rule for the arrangement of systematic rockbolting should be strictly followed.

(1) A large angle between rockbolt and constructional surface of rock mass on the tunnel section should be kept. The rockbolt should be vertical to the section where the primary constructional surface is defined.

(2) The rockbolt's placement should be arrange in diamond on the scar.

(3) The distance of the rockbolt's should not be more than 1/2 of the rockbolt length which

is about 0.5 ~ 1.0m for grade IV or V rock and no more than 1.25m.

5、《Technical specification for ground anchors》（CECS22-2005）

⑴ The workers should confirm the position of the bore and make a sign according to the request in design and sola condition before the hole is drilled

⑵ The level error should not be larger than 50mm and the perpendicularity error should not be more than 100mm with regard to the bolt distance of the drilled hole.

⑶ The deflection of the rockbolt bottom should be less than 3% of length of the rockbolt, The workers may use a declinometer to control the direction of the bore.

⑷ he drilled hole should be cleaned with fresh water before of installing the rockbolt.

Six Lectotype of rockbolt

1、The basic principle of lectotype

⑴ The anchoring strength and its characteristic curve must comply with the displacement and pressure of the wall rock to obtain the good supporting effect, low maintenance and ensure the roadway and tunnel are safely used .

⑵According to the types and the stability of the wall rocks and the condition of the roadway, the choice between prestress rockbolt, non-prestress rockbolt, end anchorage rockbolt, full-length anchoring rockbolt, mechanical rockbolt, bond rockbolt, or frictional rockbolt etc. Should be made.

⑶The type of rockbolt must also comply with the service life of the roadway. The coordination between rockbolt's serviceability, noncorrodibility and roadway, tunnel's service life should be considered.

⑷The convenience of assembling and mechanically assembling to increase the effect of the support should be considered .

2、Lectotype for hydrostatic-pressure roadway

For half hard or above hydrostatic-pressure roadway or roadway wall rock will require, the usage of prestress rockbolt, such as metal-expansion rockbolt or slit bolt or resin rockbolt and fast-hardening cement rockbolt could be considered.

When the rockbolt need to have a long service life or is in corroding environment, the corrosion resistance of the rockbolt should be considered. Prestress rockbolt with infusing common cement or other full-length-bond prestress rockbolt is recommended.

When the strength of the wall rock is low, a large anchoring strength is required. Prestress bond rockbolt should be considered as well as resin rockbolt and fast-hardening rockbolt that can bear load in early stages should be applied.

When there is frequent concussion that will weaken the anchoring strength, bond rockbolt is suggested, especially resin rockbolt or fast-hardening rockbolt.

3、Lectotype for kinetic-pressure roadway

Due to the effect from kinetic-pressure, that comes from concentration of stress in stope's, wall rock displacement and pressure increase and frequently changes will result in that the rock strata tends to strip or even collapse. For this scenario, a rockbolt with enough anchoring strength adapted to large displacement is recommended.

Rockbolt used in hydrostatic-pressure well road should have properties of prestress to some degree and full-length anchorage, especially the one with slip property, such as slittube

rockbolt.

For short-service-life rock hydrostatic-pressure well road, compressive wooden rockbolt, infusing-metal-expansion rockbolt, slit bolt, inverted-wedge rockbolt, full-length-bond resin rockbolt and fast-hardening-cement rockbolt should be considered. If the pressure and displacement is large, the usage of rockbolt's and Shotcrete rockbolt support is not enough to sustain the rock wall's stability. When this situation occurs, a shrinkable metal bear frame should be used as support structure. A yielding rockbolt is recommended for underground construction of national defense which suffering from high impact load.

For mine and semi-ingredient kinetic-pressure well road, whose strength is low and service life is short, in the area subject to the excavating-concentration of stress, the pressure and displacement are large, and frequently changes. In this case, a bolt of common wood or bamboo with certain prestress can be used. It is recommended to fill common or fast-hardening cement on the bottom of the hole, especially in areas with high pressure. Anchor wire support should also be used to strengthen the composite support structure.

4、Lectotype for soft-rock well road

If the wall is of soft rock with low strength then the soft-rock roadway has following properties of plastic deformation, creep or expansion deformation. Displacement and high pressure of the wall rock can also be noticed. For this special condition with soft wedge-in rock mass with large viscosity, high plasticity, the prestress of the rockbolt will not be good. This is because the rock mass move around the rockbolt, and only the parts that is directly contacted with the rockbolt can be well anchored.

Therefore, a full-length anchorage rockbolt that can act, as "rock mass pin" should be used in soft-rock well road, to ensure that the rockbolt is in full contact with the rock mass and will at every point prevents the rock mass from moving.

When the displacement and pressure are large, a prestress-full-length anchoring frictional rockbolt with slip property is recommended, such as slittube rockbolt, compressive wooden rockbolt or similar ones. These rockbolts do not only have the same advantage of full-length anchorage as bond rockbolt, but also the frictional anchorage is large and reliable. Furthermore, it can enhance the effect of anchorage, and coordinate large deformation of soft rock in a better way.

However, in the soft rock where the displacement and pressure are large, beside the rockbolt mentioned above, rockbolts that have large bearing capacity and compression can be used, as well as various composite support structures.

5、Lectotype for cracking and loosening wall rock

Cracking and loosening wall rocks occurs according to slump, destabilization, loosening or displacement, or if high pressure is generated. Auxiliary rods that are capable of being loading right after installation should support the bolts applied in cracking and loosening wall rock. The bolts also should have enough prestress and full-length cementation; even if they

need be installed into cracks of wall rock.

The prior selection is full-length pumping resin bolt, pumping cement bolt, etc. General bonding bolts, such as loading resin bolt, rapid hardening cement bolt, are used in cracking and loosening wall rock. Of course, all kinds of mechanical bolts used together with cement can be used.

If wall rock cracks very easily, is difficult to drill holes in, develops hole cross easily or if it sensitive to shock or vibration which will cause collapses of the wall rock, then a self-boring bolt can be selected. Using self-boring bolt, the holes can be injected without the usage of drill rods. For crack zone or water drip rock an inner injecting bolt can be selected.

Seven Rockbolt support design for mine roadway and tunnels

1、In order to decrease the effect of horizontal stress, the designer should put effort in keeping the horizontal stress direction and roadway placement parallel.

2、The roadway section should adopt rectangle and trapeze pattern, archy type may also be used in some special condition. The roadway design should meet the carrying request, its length and width may be placed 200mm apart in order to compensate the wall rock deformation.

3、The rockbolt support design should follow the dynamic feedback design method with the base on former measurements. The design steps include the calculation of geomechanics, preliminary design, monitoring and information feedback, and revised design.

4、If the calculations of the surface support the roadway and tunnel design, then the designer may begin the preliminary design.

5、Method of preliminary design

5.1、Method of computer numerical simulation,

(1) To setup a model of geomechanics with the basis from the calculations of geomechanics,

(2) To analyze the roadway deformation pattern with the base of the geomechanics model,

(3) To compare the support effect on the geomechanics model and optimize the best plan and begin to preliminary design,

(4) To analyze and confirm the critical values between the apical plate and the bottom layer.

5.2、Method of engineering analogy

When the calculation of geomechanics agrees with the geologic examination, then the preliminary design of the roadway may act as reference. According the stability of wall rock, the designer can choose, the reference project that act as the preliminary design on the basis of data in table 5. The designer must analyze and confirm the critical values with the basis of the facts gathered; the highest critical value should be smaller than 15% of the design height.

The form of rockbolt support and support parameter table 5

Tape of wall rock	The condition of Stabilization	The support form	Support parameter				
			Strength (Mpa)	diameter （mm）	anchoring force ⩾（KN）	Length	distance（mm）
Ⅰ	Stabilization	Roof	500	22	150	2200 ~ 2400	800 ~ 1100
		Side	400	20	100	1800 ~ 2200	
		Roof	500	22	150	2200 ~ 2400	900 ~ 1200
		Side	500	20 ~ 22	120 ~ 150	1800 ~ 2000	
Ⅱ	Moderation	Roof	500	22	150	2200 ~ 2400	700 ~ 1000
		Side	400	20 ~ 22	100 ~ 120	1800 ~ 2000	
		Roof	500	22	150	2200 ~ 2400	800 ~ 1100
		Side	400	20 ~ 22	100 ~ 120	1800 ~ 2000	
		Roof	600	22	180	2200 ~ 2400	900 ~ 1200
		Side	500	20 ~ 22	120 ~ 150	2000 ~ 2200	
Ⅲ	Instability	Roof	500	22	150	2200 ~ 2400	700 ~ 1000
		Side	400	20 ~ 22	100 ~ 120	1800 ~ 2000	
		Roof	500	22	150	2200 ~ 2400	800 ~ 1100
		Side	400	20 ~ 22	100 ~ 120	1800 ~ 2000	
		Roof	600	20 ~ 24	180 ~ 210	2400 ~ 2600	900 ~ 1200
		Side	500	20 ~ 22	120 ~ 150	2000 ~ 2200	
Ⅳ	Instability	Roof	500	22	150	2200 ~ 2400	700 ~ 900
		Side	400	20 ~ 22	100 ~ 120	1800 ~ 2000	
		Roof	600	22 ~ 24	180 ~ 210	2200 ~ 2400	800 ~ 1000
		Side	500	20 ~ 22	120 ~ 150	1800 ~ 2000	
		Roof	700	22 ~ 24	210 ~ 250	2400 ~ 2600	900 ~ 1100
		Side	600	22	180	2000 ~ 2200	

6、The preliminary design is an important reference for the engineers; it is also a guarantee to ensure the engineering quality. Therefore, It is the task of the deputy chief engineer to be responsible for the preliminary design, and after the design will be put in force after it has been approved. The preliminary design should have the following content:

(1) the name of roadway, location, application and planned section;

(2) the general arrangement of the rockbolt support;

(3) the support parameters (length and diameter) and mechanical parameters (strength and elongation);

(4) the parameters of the rockbolt's arrangement (distance and angle);

(5) the anchoring parameters (bore diameter and the design anchorage force);

(6) the shape of steel strap, strength and form;

(7) pretightening force and the design anchorage force;

(8) the shape of the metal gauze and format;

⑼ the consumption of the support material;

⑽ the method of the construction;

⑾ the technical measurement concerning safety, temporary support and vacant apex distance;

⑿ the observation plan of preliminary design;

⒀ the reinforcement plan on the basis of preliminary design;

⒁ Possible problems that may occurs in roadway working area as well as the solutions;

7、The roadway construction should be monitored with the basis of the preliminary design, and the monitoring answers should apply to preliminary design. When the geologic condition changed obviously, then the designer have to amend the preliminary design with the base on the data that been collected.

8、The design of special roadway section has to satisfy the need related with equipment transport, installation, aeration, and workers and should take special care when designing the safety measures. When the designer applies an anchored cable for reinforcement, a size bigger than Φ18 size is recommended.

9、The top deck design for empty roadways must combine rockbolt, wire mesh, steel strap with anchored cable and the array pitch of cable should be smaller than 3.0m.

10、The design of room and the points of intersection should be based on future possible positional connection of the adjacent roadway and tunnel section, in order to optimize roadway arrangement, reduce the damage caused from concentration of roadway stress.

11、the design of rockbolt support must be according to correlative design standards.

12、The diameter of rockbolt should match the diameter of the resin pack. The hole size should be 4～8mm bigger than rockbolt diameter, the hole for the resin pack should be 3～5mm bigger and the anchorage length calculated according to the following formula.

$$L_0 = LD_1^2 / \left(D^2 - D_2^2\right)$$

Therein: L －the length of resin pack，mm

L_0 －the anchorage length，mm

D －the hole size，mm

D_1－the diameter of resin pack，mm

D_2－the diameter of rockbolt，mm

13、The support of roadway top layer must be based on the anchorage methods of length. The design anchorage force should not be less than 150KN. The rockbolt length should not be less than 2200mm.The diameter of rockbolt body should be about Φ22 in size. The tensile strength should be more than 500Mpa. Other anchorage methods may act as extra support.

14、The design anchorage force should not be less than 100KN based on the design of side rockbolt. The diameter of the rockbolt body should be Φ20 in size. The tensile strength should be more than 400Mpa. In the roadway extraction, the position that is close to side of working

face may use a cutting rockbolt or dismantling rockbolt.

15、The both sides of the top layer must be arrange the inclined rockbolt in rectangle and trapeziform patterns. The position direction is 75° angle to horizontal direction. The worker should connect the steel strap with rockbolt.

16、The designer should preferentially use an anchored cable for the reinforcement of roadway support. The design anchoring force should not be less than 180KN and the design anchorage length not shorter than 1.0 m from outside to regular bed.

17, In order of easy field control, technical management, quality control and supporting material processing, the diameter, the length and the distance should be according to the table 6.

The series of rockbolt support table 6

Item	Series					
length（m）	1.8	2.0	2.2	2.4	2.6	
diameter（mm）	20	22	24	25		
array pitch（m）	0.7	0.8	0.9	1.0	1.1	1.2
distance（m）	0.7	0.8	0.9	1.0	1.1	1.2

Eight Inspection report of Hohai University to Roadpower-2006 FRP rockbolt

路威 2006 FRP 锚杆检测报告

生产单位：上海启鹏化工有限公司

送检单位：深圳海川工程科技有限公司

检测单位：河海大学土木学院力学实验室

一、 基本尺寸：

锚杆外径 ϕ =19.6mm　　螺纹底径 ϕ =18mm

有效直径 ϕ =18.8mm（有效面积 S=277.45mm^2）

二、 拉伸测试数据：pull test

编号	最大荷载	抗拉强度	备注
1	135KN	486MP	未坏
2	173KN	624MP	断裂
3	143KN	515MP	未坏

三、 螺母与杆体螺纹结合力

编号	最大荷载	抗拉强度	备注
1	50KN	180MP	
2	55KN	190MP	

四、 剪切测试数据 shear test

编号	最大荷载	抗剪强度	备注
1	70KN	126MP	
2	70KN	126MP	

检测：　　审核：

2005、10、9

土木工程学院

Nine Polyacrylonitrile(PAN) Fiber Shotcrete

1、Definition of Shotcrete

The definition by China National Standard and the Specifications for bolt-Shotcrete Support (GB 50086-2001): Shotcrete is a concrete forming process which uses compressed air or another power source to deliver concrete with certain mixing ratio along pipelines to spray head, to vertically spray on the plates with high speed and to form compact concrete by continuously usage of cement as an base material.

The definition by America Cement Institute (ACI): Shotcrete is a mortar or concrete forming process which uses compressed air to spray it onto a plate with high speed.

2、Classification of Shotcrete

According to the different construction processes, the Shotcrete is classified as dry shot concrete, wet shot concrete and cement-sand shot concrete. It can still be subdivided according to different blending composition. At present, dry shot and wet shot are common construction processes. Normal shotcrete, synthetic fiber shotcrete, steel fiber shotcrete and wollastonite shotcrete are commonly used shotcrete.

3、Main characteristics of shotcrete

Shotcrete is a special process in concrete construction. The significant characteristic is the spray process by compressed air with high speed.

The speed from the nozzle is high, about 60-80m/s. During the spray process, cement and base material strikes continuously to form compact concrete. Therefore, shotcrete has good mechanical properties and strong adhesive strength on rock, steel as well as on old concrete structure.

In geotechnical engineering, shotcrete is not only used to reinforce but is also used to connect the bolt with supporting parts. Shotcrete has become the main technique used in geotechnical engineering.

Shotcrete can be used widely but must be changed to adapt undesirable geological conditions, such as loosening expanding rocks, cracking rock with joint fissures, and even water spray rock. When meeting with the above-mentioned undesirable geological conditions, extra measures must be done to make the application of shotcrete efficient. At present, shotcrete is successfully applied in several engineering fields, such as sinking and driving engineering, traffic or hydraulic tunnel liner plate, underground power station liner plate, underground support engineering, etc.

4、Polyacrylonitrile(PAN) Fiber Shotcrete

PAN fiber was developed and patented as micro-strengthening rib by Dupont in the middle of 1970s. At present, PAN fiber has been promoted to many countries and areas and its good performance has attracted more and more customers. Oceanpower Engineering Technology Co., Ltd introduced it to China in early 1990s, and now over one hundred projects in China is using or have been using the PAN fiber.

4.1 Material characteristics of PAN fiber

Water absorbability: < 2%；
Gravity: 1.18
Length of the fiber net: 6、12、24mm;
Melting point：220℃；
Low thermal conductivity;
High acid-base resistance;
Tension strength：500-650MPa；
Elastic modulus：7-9Gpa；
Safety: non-toxic material.

4.2 PAN fiber and advantages in shotcrete

The engineering quality can greatly be improved when applying PAN fiber and this is why PAN fiber shotcrete has been promoted all over the world since 1980s. The following are the main advantages of PAN fiber shotcrete:

⑴Capable of forming a thicker shotcrete film.

⑵ Has higher viscosity, capable of decreasing rebound concrete and there though reduce cost.

⑶Capable of preventing concrete from shrinking or cracking.

⑷Capable of increase the shock resistance.

⑸Capable of enhancing flexural strength.

⑹Capable of increasing fatigue resistance up to 3 times.

⑺ By Using PAN fiber shotcrete the jet initial velocity can be reduce up to 70~80% compared to other materials. This will decreases the shock force and enhances the strength of the concrete.

⑻ It is easy to transport and to be delivered, and will not damage mechanical facilities.

⑼ PAN fiber can resist acid-based corrosion and can prevent aging corrosion effectively.

⑽It can improve the water binding ability of the concrete to protect main rib structure and there through prolong the service life of the concrete.

⑾There is no need of changing the original concrete mixing ratio when adding PAN fiber.

⑿Compared with wire net, PAN fiber is easier to store, transport and use.

⒀PAN fibers spread in concrete homogeneously and will be disordered in all three dimensions.

4.3 Construction of PAN fiber shotcrete

Directions for PAN fiber application

⑴Proper fiber length: Oceanpower Engineering recommend the usage of 12mm long fibers in concrete.

⑵Mixing precedence: The mixing precedence of PAN fiber is not limited and it can be mixed before, during or after other material been added or at the same time together with other material is added. The addition quantity is 0.9kg/m^3.

⑶Mixing time: It is enough to stir 1min and it will not have influence on the fiber distribution and strength that may be caused by the prolonged mixing time.

⑷Mixture ratio design: Since the strengthening mechanism of PAN fiber is not chemical action but an mechanical action, therefore the mixing rates when the PAN fiber is added do not need to be changed if compared original mixture ratio.

Construction of PAN fiber shotcrete

Oceanpower Engineering recommends damp or wet blasting when applied in constructions since it is more convenient than dry blasting. The particle size and water cement ratio must be strictly controlled in dry blasting process. The particle size cannot bigger than 4.75mm and the water cement ratio must be followed strictly, otherwise high-qualified application cannot be achieved. Compared to wet blasting process the only controls needed is the water cement ratio that should be between 0.35 and 0.45 and that there is 5% of 0.9kg/m^3 PAN fiber addition, to decrease the friction resistance and there though reduce the pumping pressure.

4.4 Effect analysis

Many researches and investigations have been carried out in concrete engineering and comparisons have been made between steel fiber, glass fiber and PAN fiber. The investigation report from G.W.Frank is a typical example, and bellow is the main points from the report:

⑴In general, Glass fiber is not recommended to shotcrete, except in special cases concerning silica aging protection caused by base corrosion or other reason.

⑵When steel fibers are added into concrete with high water cement ratio, the concrete conductivity increases. And it may increase electrochemical corrosion.

⑶PAN fiber is non-corrosive filling material, and it can effectively prevent concrete from shrinking and cracking due to its good chemical resistance on mineral, acid or base material, and inorganic salt.

⑷Although it is not noticeable, the compression strength of fiber shotcrete is obviously different from that of non-fiber shotcrete. Furthermore, the good performance of fiber shotcrete related to its flexural strength is of deep interest for engineers.

⑸Compared with AR glass fiber concrete, PAN fiber concrete has far better compression strength and both in 7d experiments and in 28d experiments. As to the comparison with steel fiber concrete, PAN fiber has the better performance on flexural strength, but has the lower performance on compression strength. It must be emphasized that steel fiber also has some fatal weakness in practical application, such as high cost, severe damage to blasting spraying equipment, difficulty of uniform mixture and corrosion.

4.5 Application examples

In 1985, the Swedish National Academy carried out a study to compare the performance of steel fiber shotcrete, synthetic fiber shotcrete, and common shotcrete. The result showed that the compression strength of concrete with fibers was 34% higher than concrete without fibers and the flexural strength was 46% higher. The rebind tests in mine reinforcement engineering applications is 25% without fiber addition, 10% with steel fiber addition, and 4~5% with synthetic fiber addition.

⑴The addition fibers of the reinforcement shotcrete in canal flood protection engineering in Arizona US do not use steel fibers but synthetic fibers. And the spraying thickness is 100-150mm.

⑵In 1980, American Mexico government built two fast flowing flood passages. One was constructed with traditional steel concrete and the other was constructed with synthetic fiber concrete in order to compare the performance. Based on later estimations, the synthetic fiber concrete economized 25% of the investment.

⑶The new tunneling construction in Hong Kong used synthetic fiber concrete and replaced the traditional steel concrete from aspects related to environment protection, electric power and commercial service, etc. The spraying thickness was 75mm, and had good engineering results.

⑷Synthetic fiber concrete was successfully used to reinforce the heading slope of the cave door and the preliminary bracing of the cave in a tunneling construction in Philippine.

4.6 Conclusion

In recent years, PAN fiber application has been developed gradually in China. There are many successful projects in Guangdong, Shangdong, Shanxi, Henan, Henbei, Hubei and Shanghai since 1998. It is certain that the reinforcing technology in concrete using PAN fiber will be applied more and more frequently in future construction projects.