Proposals for the Optimization of Steel Bars in Construction

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<Abstract> In China, a wide variety of steel bars have been used as reinforcements in concrete structures, however, their strength only lean towards low and ductility of some of these bars may be too bad, hence, they can hardly meet requirements of the development of concrete structure. On the basis of the main requirements of load-bearing reinforcements in concrete structures, an analytical comparison between strength, ductility, stability of quality, anchoring performance, suitability of construction and economics etc. of existing steel bar has been made. According to the national conditions of China and the great changes of building construction market at present, some proposals concerning the popularization of grade III steel bar and high-strength wires and strands, development of small diameter grade II, III steel bars, optimization or elimination of cold drawn steel bars and further advances on forming a complete set of technology for reinforcement of steel bars etc. are also presented. This paper is also provided for the references of building design department and metallurgical enterprises.

1 Brief Introduction

1.1 Developments and present situations of concrete reinforcements

In China, the development of concrete steel bars has gone through three stages: that is, in nineteen fifties and sixties, copy production of the former Soviet Union's smooth surface, contour edged steel bars such as helical and chevron bars, as well as steel wire of seven strands; secondly in the nineteen seventies and eighties, when the low alloy and cold processed steel bars were developed, steel bars with meniscus edges and cold drawn steel bars and wires were developed and produced; the third period is nineteen nineties, the international standards were adopted for producing various medium and high strength steel wires and strands, and the production range of cold processed steel bar were expanded to include ribbed bars of cold rolled, twisted and helical ribs. The historical reasons have resulted in the present situations that both new and old steel bars are available in the market, and there are a lot of brands of them.

1.2 Varieties and basic performance of steel bars existing in China

There are three varieties of steel bars in China, that is: cold draw steel bar from hot rolled steel, medium and high strength steel wires and strands as well as cold processed steel bars. The basic performances are listed in Table 1, 2 and 3.

Table 1 Basic performance of cold draw steel bars

Grade	Brand	Dimension d mm	Yield strength f_y Mpa	Tensile strength F_b MPa	Elongation δ s%	Shape	Cold bending (angle Φ)
I	HPB235	8-20	235	370	25	Smoth surface	180° d
II	Cold draw	≤12	280	370	11		180° 3d
II	HRB335	6-25	335	490	16	Meniscus edged	180° 3d
		28-50					180° 4d
	Cold draw	≤25	450	510	10		90° 4d
III	HRB400	6-25	400	570	14	Meniscus edged	180° 4d
		28-50					180° 5d
	Cold draw	8-40	500	570	8		90° 5d
IV	HRB500	6-25	500	835	10	Meniscus edged	180° 6d
		28-50					180° 7d
	RL540 Cold draw	10-28	700	835	6	Contour edged	90° 5d

Table 2 Basic performance of medium and high strength steel wires and strands

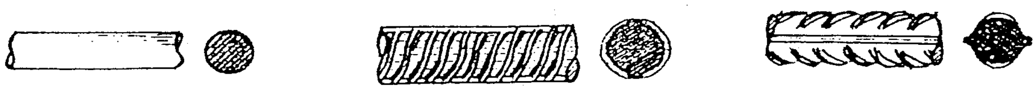
Types	Brand	Dimension d mm	Yield strength $F_{0.2}$ Mpa	Tensile strength F_b MPa	Elongation δ_{100} %	Shape	Cold bending (angle, times)
Low alloy steel Wire	YD800	5	—	800	4	Smooth surface with indents	180^{o} 4
	YD1000	7		1000	3.5		
	YD1200	7		1200	3.5		
Heat treated steel bar	RB150	68.210	1325	1470	6(δ_{100} %)	Meniscus	—
Pre- stressed Steel rod	Profiled	7.1-12.6	930- 1275	1080-1230	5	Helical groove	—
	Smooth surface	9.2~19.0				Smooth surface	
Pre- stressed steel Wire	Steel wire with stress relieved	4~9	620~1500	800~1770	3~4	Smooth surface	180^{o} 3~5
	Indented steel wire					With indents	
	Helical ribbed steel wire					Helical rib	
Pre- stressed Steel strands	Two strands	5-12	1250~1580	470~ 1860	3.5	Rope	—
	Three strands	6.2-12.9					
	Seven strands	9.5-15.2					

Table 3 Basic performance of cold processed steel bars

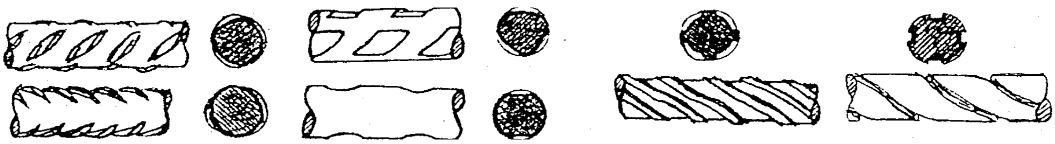
Types			Dimension d mm	Yield strength $f_{0.2}$ Mpa	Tensile strength F_b MPa	Elongation δ_{100} %	Shape	Cold bending (angle, times)
Cold-drawn Low-Carbon Steel wire	A	I	4	—	700	2.5	Smooth Surface	180^{o} 4
			5		650	3.0		
		II	4		650	2.5		
			5		600	3.0		
	B		3~5		550	2.0		
Cold twisted bar			6.5~12	—	580	4.5(δ_{10} %)	Twisted rectangular, rhombic	180^{o} 3d
Cold ribbed bars			4~12	500	550	8(δ_{10} %)	Meniscus	180^{o} 3d
Helical ribbed bars			4~6	520	650	4	Rib (two, three sides)	180^{o} 3d
			5	640	800	4	Helical rib	180^{o} 3d

1.3 Shape and geometric features of steel bars

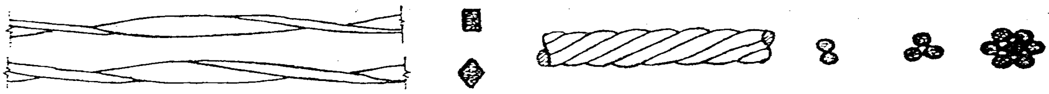
(1) Profile of rebars: There are six kinds of shapes of steel bars in China , which are smooth surface , ribbed surface, indented surface, twisted, helical and rope shape as illustrated in Figure 1.



(a)smooth surface steel bar (wire) (b)deformed bar of contour edge (chevron, helical) (c)bar with meniscus ribs



(d) cold rolled ribbed bar (e)steel wire with indents (f)steel wire with helical ribs (g)steel wire with helical groove



(h)cold rolled, trwisted ribs (rectangular, rhombic) (i) steel strands (two, three, seven plies)

Figure 1 Various shapes of steel bars

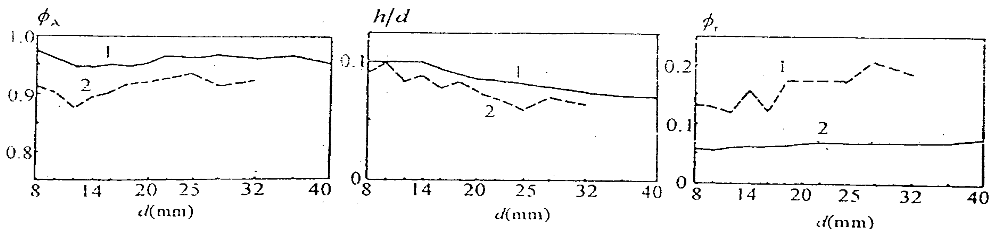


Figure 2 Geometric performance of hot rolled, cold drawn bar

1- meniscus edged 2- contour ribs

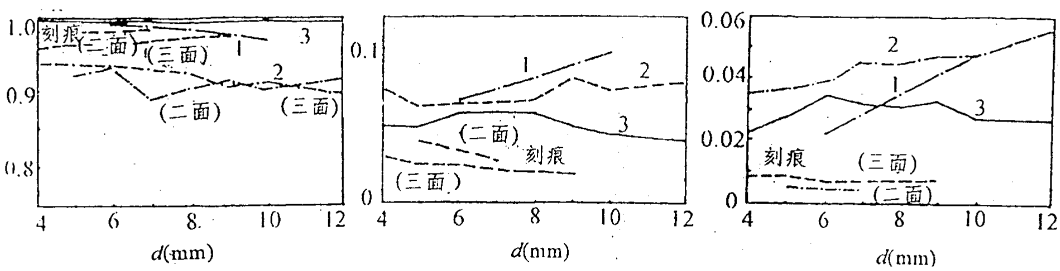


Figure 3 Geometrical performance of steel wire and cold processed bar

1-meniscus 2- cold rolled rib 3-helical rib

(2) Geometric characteristics of steel bars

Three main parameters in relation with the performance of steel bars can be calculated from the outside dimensions resulted from standards of steel bars:

$ø_A$: the area ratio of base circle: that is, the proportion of efficient, axial force bearing cross section of bar, which is concluded after the non force-bearing parts such as the ribbed surface being deducted. This force bearing section is in relation with the strength of steel bars.

h/d: relative height of protruding traverse ribs: the rate between the protruding traverse ribs or the grooves and nominal diameter of steel bars; this is in relation with the anchoring performances.

$Ø_r$: area ratio of ribs: the rate between the projected area of traverse section of the protruding ribs or the groove and the superficial area; this is in relation with the anchoring performance.

The other geometric parameters are: angles between ribs (or groove) and bar axes, tilting angle of ribbed surface or groove, slot pitches between ribs or grooves etc.; all these are in relation with the anchoring performance. Main geometrical performances of various bars are illustrated in figure 2 and 3.

1.4 Proposals for optimization of construction reinforcements

Because of historical reason, there is a large variety of reinforced bars in China. This in many cases has caused confusion in application and cannot meet requirements of the development of the construction market and concrete structures. Therefore, it is quite necessary to optimize the existing steel bars through comparison and study. This paper is trying to put emphasis on analysis of the performance of steel bar and to give out suggests on how to make optimization.

2 Performance of steel bar required from concrete structure

2.1 Strength

The strength of steel bar is the main factor to determine the force-bearing of concrete structure. Generally speaking, the higher the strength of reinforced structure, the safer it is. Therefore, the adoption of high strength steel bar instead of high rate of bar distrubutions is the right way to go. Since the elastic modulus of steel bar is basically a constant, when the high strength reinforced bars are bearing forces under high stress, the structures often deform and crack, therefore, the design strength limit of normal concrete structure is 360 Mpa; too high strength is meaningless. This problem is solved by pre-stressed structure. The high strength of steel bar can be effected through stretching bars to apply pre-stress on concrete. However, at the same time, there is a problem, that is, the concrete is bearing forces together with bars. Limited by the strength of concrete, the steel bar with too high stress is hard for anchoring, consequently the bar strength cannot function well. Therefore, there is a limit to the high strength of steel wire and strands, of which, the highest should not exceed 1860 Mpa.

2.2 Ductility

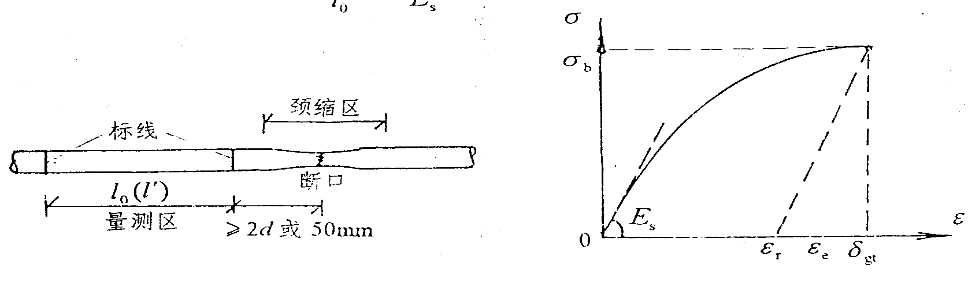
Ductility is the capacity that steel bar deforms and consumes energies. It is as important as the strength. Investigation shows that many accidents, especially severe accidents are caused by insufficient ductility, which caused brittle fracture, instead of by insufficient strength. Normally, ductility of steel bar is expressed by elongation, which is calculated on the base of relative deformation measured from the fracture of steel bar. If the measuring gauge length is different, for example 5d, 10d and 100mm, then there are three kinds of elongations like δ_5 δ_{10} δ_{100}. It is hard to compare them because the measuring length varies; secondly, the fracture elongation only reflects the residue deformation of the necking and the fracture, which is quite different from the strain condition occurring at the time of fracturing; moreover, the measuring error range is wide when the measurement is carried out on a matched fracture, thus the results cannot reflect the true ductility. Therefore the present measuring method for elongation has caused some confusion in the conception. It is quite necessary to be modified and united. Under normal laboratory condition, on a tested sample, the residue strain, $\varepsilon_r=(1^1-l_0)/l_0$ (in which, the 1^1 refers to the residue length), measured in the non-necked length labeled with l_0 in figure 4(a), after plus together the recovered elastic strain $\varepsilon_e=/E_s$ (in which, σ_b^0 is the fracture strength practically measured, E_s is the elastic modulus), we can get the total elongation (simply called uniform elongation) under maximum action force. δ_{gt} is considered as the index for the ductility of steel bars. The uniform elongation (δ_{gt}) authentically reflects the average (not partial area) elongation of bar before necking fracture occurs, as well as that of the deformation of steel bar. It is comparatively the scientific index for ductility.

The ratio of yield strength also reflects the ductility of steel bars. Quake-proof structures require that the ratio between strength and yield of force bearing bar should not be less than 1.30.

2.3 Stability of quality

The stability of mechanical performance of steel bar is very important. For the steel bars produced in large scale, the deviations of ductility and strength are small; and the homogeneity is good; the performance is stable and the quality is guaranteed. However, after being secondarily processed, for example, cold pulled and drawn, cold rolled or cold twisted, the discrete degree is increased, the quality is unstable. Especially, for those produced in small workshop, since the base material (wire coil) in China is generally too crude, and also the process is primary; and there is a lack of efficient technological management and strict quality inspection,

$$\delta_{gt}=\frac{l'-l_0}{l_0}+\frac{\sigma_b^0}{E_s} \quad (1)$$



(a)Sample and the measuring pitches **(b) Tensile curve and uniform elongation**

Figure 4 Measurement of the uniform elongation of steel bar

therefore, the quality fluctuates sharply, and the unqualified rate is high, which, in turn, are always the factors that affects the safety of reinforced structures.

2.4 Anchoring performance

The anchoring performance is the base capacity of steel bars to bear force in concrete structure. It includes anchoring rigidity, anchoring strength as well as the anchoring ductility. Herein the anchoring rigidity is the capability to restrict slips, the anchoring strength is the maximum anchoring stress, and the anchoring ductility is the capability to retain anchorage when there are too much slip occurrences. Normally, this is comprehensively reflected by the anchorage stress—slips (Γ — s) curves which are measured during test of the anchoring bars (figure 5).

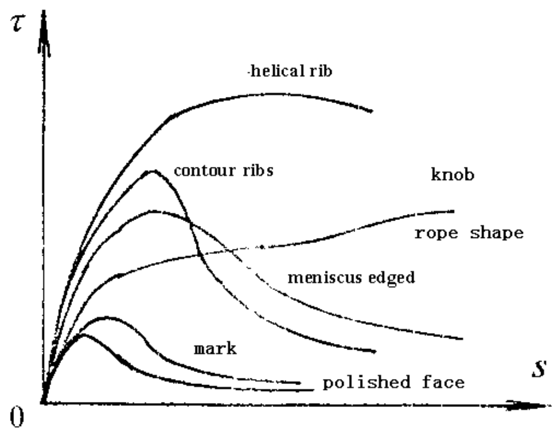


Figure 5 Γ —s Curves of various bars

Mainly, the anchorage functions as the seizing ability, which is formed by the squeezing between the transverse ribs and the holding-on teeth of concrete which takes its shape in between of transverse ribs. The formation of the seizing ability is in close relation with height of ribs, area ratio of ribs and the shape of the holding-on teeth. The oblique (inclined) squeezing (between concrete and bars) finally results in the splitting of concrete along longitudinal direction of bars. The anchorage is thus being decreased. When the slip is severe, the holding-on teeth will be broken and the anchorage is damaged. The splitting force only happens at the traverse ribs. Therefore, as for the asymmetrical cross sections of meniscus ribs and cold ribbed bars, the split always occurs in certain direction (figure 6).

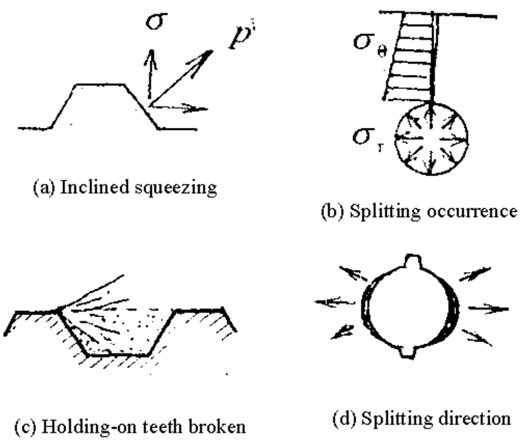


Figure 6 Seizing force and anchorage damaging

The smooth surface of steel bar is easy to have slips, it has low anchorage strength and bad ductility; as for the steel wire with indents or helical groove, the concrete teeth formed on them are too thin, hence it has no big difference from the smooth bars; while for the deformed bar with contour ribs, the formed teeth is very deep, the anchorage rigidity and strength are high, but the anchorage ductility is bad; as for bars with meniscus ribs and cold rolled, ribbed bars, though the anchorage ductility is good, the anchorage rigidity and strength are a bit lower, and what's more, the splitting occurs in certain direction; as for steel strand and cold rolled, twisted ribs, since the seizing force is generated by the squeezing of the side-twisted angles, the anchorage ductility is fine, but the anchorage rigidity and strength are low; steel wire with helical ribs has the sustained stress from the squeezing of the transverse ribs, and the formed concrete teeth are relatively wide and big, the formation is a consistent helical shape, the anchorage rigidity, strength and ductility are all good, therefore it is the desired shape of steel bars.

The anchorage performance of steel bars is expressed as anchored length [l_a] in design. This refers to the length of steel bar that has to be anchored into the concrete for well functioning of the design strength. The better the anchorage performance of steel bar is, the shorter length to be immerged into the concrete, otherwise the immerged length would be longer. Smooth bar that has bad anchorage performance must be bended into hooks at the ends to have mechanical sustaining force.

Through concrete anchorage, self anchored and pre-stressed steel bar can establish the designed pr-stress value. The required length for building up the designed pr-stress value is the transferring length of the pre-stress [l_{tr}]. Through measuring the strain (ε e) distribution caused by the pressure applied on the ends of fabricated structure, we can get the transferring length value. The steel bars that have better anchorage performance have shorter transferring length, that means, within short length range, the design required pre-stress value is established. However, too short transferring length will result in concentration of stresses at the ends of the fabricated structure and will cause partial squeezed crackles.

2.5 Fatigue performance

Crane girder and fabricated structures used in transportation fields such as roads, bridges that bear repeated loads have requirements for fatigue performance. Generally speaking, steel bars with smooth surface have better fatigue performance. While steel bar with irregular shape is tended to cause stresses centralized at places of the abruptly changed shape, thus induce fatigue destruction.

2.6 Durability

Whether steel bar is sensitive to corrosion or not, this depends on both the size of the bar diameter and whether it is pre-stressed bar or not; the smaller the diameter, the greater influence imposed on resistant force by the corroded sections; for the pre-stressed bar bearing force under high stresses, the stress corrosion influence is relatively large. Therefore, anti-corrosion should be especially emphasized for those steel wires, strands and cold processed bars that are used in pre-stress fabricated structures. Corrosion has much relation with the environment. Those steel bars having better anti-corrosion performance may be used in concrete structures underneath foul condition and high durability requirements such as water, harbor, chemical and municipal civil projects

2.7 Weldablity

The weld performance of steel bars depends on the contents of carbon and various alloy elements in the base materials. The higher the carbon equivalent is, the less possibility to be welded. When the carbon equivalent exceeds 0.55%, it is hard to be welded. Hot rolled bars can be welded, but the steel wires and strands of the high strength cannot be welded. For the other high strength bars and those bars strengthened through heated treatment and cold processing, if the carbon equivalent is within certain range, it is possible to be welded. But, the strength in the weld zone will be become a little bit lower, necessary measures should be taken. Spot weld affects the strength not much; therefore, small diameter bars are always spot-welded into rib mesh for using in the projects.

2.8 Manufacturing ability

Manufacture ability refers to the quality for cold processing at construction site and adaptability to construction. There are several aspects to be described as follows.

1)Cold processing quality

Under double control of stress and deformation, improvement of strength by cold drawing the hot rolled bars normally is carried out at the same time of straightening. The ductility for cold drawn bar becomes lower, but the change is not much, and seldom causes brittle facture. However, cold drawing, cold rolling and cold twisting drastically change the sections and the shape, although the strength is improved, the ductility loses a lot. Since the base material quality varies, and the diameter is a little big, after processed, the area shrinkage is a bit lower. Therefore not only the ductility of cold rolled bar is low, the quality of it is also unstable. In 1998, the national inspection center of construction steels carried out an inspection on the production license for producing cold rolled ribbed bars. The inspection result shows that over one third of the producers is unqualified. Among them, grade LL550 and LL650 steel bar are unqualified because of elongation, they amounts to 22.2 % and 23.8% respectively; while grade LL800 steel bar is unqualified due to its strength, this takes about 30.0%. Especially, for grade LL650 steel bar that is widely used in pre-stressed orifice plate, when guarantee rate calculated at 95%, the elongation is only 3.1%, which constrainedly reach the qualification standards of cold drawn wire. Moreover, a lot of producers without licenses produce blindly. It is hardly to be optimistic about the quality condition of cold processed steel bars in the countrywide.

2)Cold bending performance

When bending, hooking steel bars, crack and fracture occurrences should be avoided. The hot-rolled bars of low strength have better cold bending capacity than those of higher strength; cold processed steel bar is easy to break, hence the cold bending performance is the worst. Since the cold twisted rib is constrained by its directional section, it can only be bended once alone the flatting direction, the adaptability for construction is therefore restrained.

3)Rigidity of framework rib mesh

Framework rib meshes at construction site are often deformed and displaced because of construction disturbance, thus the structure performance is affected, or even worse it cause accident. Mostly the small diameter bar can easily cause problem. While the cold twisted bars are forceful, the rigidity of framework formed from this kind of steel is great, therefore it is not easily deformed, it is suitable for casting stringboard. For welded rib mesh, the rigidity of the framework is also good.

2.9 Delivery condition and construction sequences

Hot rolled and cold drawn steel bars above 12 mm in diameter are delivered in straight bar, when cutting to length, some remain are produced, many joints are brought out during fabricating the reinforcement structure. The small diameter bar, wire and strand can be delivered in coils, and can be cut to required length to reduce joints. The smooth bar has to be hooked at the ends. When stretching pre-stressed bar, the ends often need to be in pier shape, or be anchored with clamps. As for cold drawn wire and cold rolled ribbed bar, before fabricating as non pr-stressed bar, they have to be straightened first; part of the strength will lose. Cold twisting process is integrated with rolling, straightening and cutting to length, and is convenient for site construction.

2.10 Financial condition

The index to judge whether steel bar is economical or not is that the ratio between strength and price (Mpa．t /　RMB yuan) that is to say, how much design strength of unit bar can be purchased with one Chinese yuan? The higher the ratio between strength and price, the more economical it is. If calculated with the market price at the end of 1998, the ratio between strength and price of grade I, II, III steel bar is 0.09 — 0.13; the ratio for medium and high strength wire and strand is 0.20—0.24; the ratio of cold processed steel bar without pre-stress is 0.09—0.12; while the cold processed steel bar with pre-stress is 0.14—0.16.

3 Current development of construction steel bar outside of China

3.1 Strength improved

Varieties and specifications of hot rolled steel bars outside of China gradually come into integration. The strength grades are divided into 300, 400, 500 MPa. Steel bar of grade 400 MPa has become the main force bearing bar; Grade 200 MPa is tended to be eliminated; Grade 500 MPa has begun coming into use. The pre-stressed fabricating structures have abandoned using of cold processed steel bar, instead, medium and high strength steel wire and strands are completely adopted, the tendency is likely to use steel bar of high strength for example 1860 MPa, and low slack about 2.5%.

3.2 Emphasis on comprehensive performance

Attention has been paid to the improvement of the comprehensive performance of steel bar. Apart from strength, ductility has gained enough value. Many international standards have classified steel bars with regard to their ductility: The minimum uniform elongation of cold processed steel is greater than or equal to ($\delta_{gt} \geq$) 2－2．5％. While the elongation for high ductility steel bar is greater than or equal to ($\delta_{gt} \geq$)5－6％.

3.3 Development of relative technology of steel bar

Great improvements are made in technologies like mechanical connection for bars, high efficient anchor and clamps, connector for pre-stresses and their relative devices, no coherence pre-stress structure, high efficient prefabricated structure with pre-stress, application of welded rib mesh and framework, as well as the technologies of mesh mould, epoxy-coated steel bar and anti-corrosion

4 Proper selection of steel bars for concrete structure

4.1 Steel bar of grade III will be dominant.

Grade II steel bar was mainly used for force bearing in the traditional concrete structures in China. Grade I steel bar was used as steel hoop and auxiliary fabricating. In this case, the ratio of reinforcement was high. On the other hand, strength of the concrete used was low. This resulted in plump beam, huge column, deep base and thick wall, which in turn added weights on the structure and amounts of construction works. In the future, grade III steel bar of 400 MPa will become dominant, the design strength is 360 MPa. The ratio of strength and price is 0.13Mpa.t / RMB yuan, which is 15 % higher than the grade II steel bar and cold processed steel bar. If vanadium nitride process is adopted, the cost can be decreased, it is only 100 – 150 yuan higher than grade II steel bar. In this way, the ratio of reinforcements can be reduced greatly; the structure weight and construction works can be reduced, too. The construction difficulty will be avoided in the tensely integrated reinforcements.

Grade III steel bar has good ductility. The uniform elongation is greater than or equal to ($\delta_{gt} \geq$) 10%, and the ratio of yield strength is greater than or equal to ($\sigma_b / \sigma_y \geq$)1.30, which is much higher than that of various cold processed steel bar. Under accidental overload, earthquake and other accident conditions, no brittle facture happens. It can be used in anti-earthquake structure with consideration to redistribution of plasticity internal force in plasticity design.

4.2 The application prospects of small diameter hot rolled steel bar

The steel band and conjunct bars in concrete wall and plate are mainly thin steel bar, of which the diameter is less than Φ12. Besides, the frame vertical bars, fabricating bars, distributing bars as well as anti-crack, surface layer-used bar are all thin steel bars. The used amount of thin steel bar accounts to 20-25 % of the total steel bar usages. In future, when the residential construction become dominate in the market, there will be a large increase in using conjunct bars in concrete wall and plate; the anti-crack steel bar used in surface layer will also increase. Therefore, the quantity of thin steel bar will be increased in large scale.

In the past, thin steel bar normally was not produced in metallurgical field. Thin steel bar used in civil construction was cold processed from the purchased coils of grade II steel. This cold processed steel bar is unstable in quality and has increased processing costs. The newly revised standard GB/T1499 has exerted use of grade II, III hot rolled steel bars with diameter of 6, 8, 10 mm. Since steel bars produced in large scale have stable quality and excellent performance and lower price than cold processed steel bar, they will gradually replace grade I steel coil of low strength and various cold processed steel bars, and will become the leading variety in thin steel bar. They are bound to have considerable market prospects.

4.3 Application of Grade III steel bar

As far as the grade III steel bar of 400 MPa is concerned, the trial production was finished in the middle of the 1980s; research of the relative application technology was finished by the end of eighties; at the beginning of the nineties, regulations concerning the application technology was compiled, that is the standards of the former metallurgical ministry, which, In 1996, was officially included in the partially revised design regulations for concrete structure. It is even listed as the first force-baring bar in the revised design regulations in 2000. However, in recent years, grade III steel bar is not widely used, the existing production capacity cannot be developed properly. The main reasons are that the dissemination is not sufficient; the design people do not know about it; and there is a lack of relative matching design program and efficient promotion measures from the metallurgical departments as well as communications between metallurgical and construction departments.

The newly revised design standards explicitly clarify that grade III steel bar will be the main force-bearing steel bar in structures; various cold processed steel bars, such as cold pulled cold drawn and cold twisted, will no longer be listed in the national standards, they will be managed by industry regulations; there will also be some modifications to the limit of design strength of steel bar and ratio of reinforcements. All these measures will promote wide application of grade III steel bar. With publication and effect of the standards, and the linked promotions from metallurgical and construction departments, grade III steel bar will be the dominant bars in concrete structure. These changes should be expedited to improve the safety reserve and the technology level of concrete structure in China.

5 Proper selection of steel bars to be used in pre-stressed concrete structure

5.1 Present condition of pre-stressed bars

Pre-stressed steel bar has long been used in China, but remained at lower stage. Except few large sized structures are pr-fabricated with high strength steel wire of seven strands in post stress mode, a large majority of pre-fabricated structures are produced with cold processed steel bars such as cold pulled steel bar of grade II, IV and cold drawn low carbon steel wire. In recent year, no coherence pre-stress technology is widely used in the structure. In prefabricated structures, cold pulled steel bar are gradually replaced by indented steel bar of high strength; and cold drawn steel wire are replaced by cold twisted, ribbed steel bar. But there are still many problems existing in the application of pre-stressed steel bar. The comments are as follows.

5.2 Cold processed steel bar is not suitable for pre-stress fabrication.

Cold processed steel bar is the outcome of makeshift measures during the state planning economy when steel products were in extreme shortage. With much sacrifice of ductility (δ_{gt}) from 20 % down to 2%, the strength is limitedly reached to 70% in return; the production is in small workshop scale, the product quality is extremely unstable. Cold drawn wire has lower strength and bad ductility as well as bad anchorage performance; cold rolled, ribbed steel bar has small area ratio of base circle and lower qualification rate, and moreover, improvement of anchorage performance often conceals the increment of cracks which result in brittle fracture without any omen; cold pulled steel bar has strength limitedly improved but the ductility becomes worse, brittle fracture always occurs at ends in pier shape, therefore, pre-stress cannot be applied. With short supply and instability of the commodity, it can hardly go on any further. There are also various cold processed steel bars outside of China such as cold ribbed and twisted steel bars, but there is clarified ductility requirements, for example, uniform elongation (δ gt) is somewhat equal to or greater than 2－2.5 ％, and they are only used as non pre-stress steel bar, never used as pre-stress fabricating bars; When pre-stress steel bar is stretched, the initial point of stress for bearing force is high around 0.7 f_{ptk} (?), the remain room for stress increment is not much; the stress pr-applied （ б pc ） will result in delayed cracks and large rigidity, and some steel bars have strong ability in control of cracks, when the deflection and cracks are not obvious, brittle fracture always happens without any omens due to the rupture of steel bars, this can be called as "brittle structure". In China, cold processedsteel bars have insufficient strength that may be between 500—800 MPa and bad ductility below 2%, when they are used as pre-stressed bar for fabricating floor plate, they are subjected to cause floor rupture, which takes considerable portions of severe accidents. This situation formed in history should be changed as soon as possible. The replacement of cold processed steel bars with high efficient pre-stress steel bar is imperative under the situation.

5.3 The optimization of high efficient pre-stresses steel bar

Apart from cold processed steel bars, the traditional pre-stressed steel bars are seven strand wire and smooth surface or high strength steel wire with two sides indented. The former can only be used in large sized structures that have large section; the latter establishes pre-stress by anchoring clamps or long transmitting length, which limits wide application of pre-stress. In recent years in China, international standards are implemented to produce steel wire of high strength and low slack. The mechanic performance excelled the traditional pre-stressed steel bar greatly. Two stand and three strand wires are added to the varieties to make the pre-stressed steel bar small sized and having better anchoring performance; they are suitable to be used as pre-stressed bar for pre-stretching medium sized structures. Strengths of steel wire also have formed into series like medium strength between 800—1370 MPa, and high strength between 1470—1870 MPa, which can meet requirements of various types of structure. The out shape of steel wire is also tended to be diversified; three-side indented, helical ribbed, helical groove steel wires can be applied in pre-stretched and self anchored form instead of using anchoring clamps. Especially for the helical ribbed steel wire developed by the country's own effort, because of its large base circle area and excellent anchoring performance, it is widely welcomed. It most probably will replace other types of steel wire to become the first selection of pre-stress steel wire in the future.

5.4 Some problems concerning the applications of high efficient, pre-stress rebar

High and medium strength steel wire and strand have high strength between 1270—1860 MPa and good ductility equal and more than 4—5 %. The ratios between strength and price are more than 0.2 MPa.t/ RMB yuan, about 30 – 40 % higher than cold processed steel bar. Currently, the basic research work has been finished and engineering application has begun. They are mainly used for site-casting the concrete structure in no coherence pre-stress after-stretched form, or pre-fabricated into pr-stressed frame for fitting structures. They are in long span, and can shoulder heavy loads. They have high anti-crack capacity, good control of cracks (thin and dense). The recovery capability is also strong, that is, after unloaded, the deflection recovers, and the crack is closed. The ductility is so good that brittle fracture never occurs, thus it is called as "toughness structures ". The problem is that after crack happens, the rigidity degrades obviously. Since high strength causes high stress and great deformation, the deflection increases rapidly. This is the common weakness shared by the high efficient pre-stressed structures that relatively have slender section. After the materials being strengthened, rigidity deformation may replace force-bearing, and become the key factor in control design. Besides, there are some inescapable problems in application like connection and patch of pre-fabricated structures, integration of fitting structures and anti-earthquake capacity. It is necessary to conduct relative test and research, and compile necessary regulations, application guidelines and standard drawings to direct the design and construction works. Only after the relative technology is developed, can the application be popularized.

Currently, residential building is being built into long span that can be flexibly segregated. The traditional pre-fabricated structure with cold processed steel bar can hardly meet the changes and are to be eliminated. The replacing stringboard that is cast at the site has limit in span and load bearing, and can hardly provide a real long span for each household, and moreover, it is limited by shrink cracks from concrete temperature. Fabricating integral stringboard or superposed stringboard with steel bar of high strength and high efficient pre-stress may successfully solve the above mentioned issues, and may become the ideal mode of residence with stringboard of long span. Residential building will dominate the future construction market. The application of high efficient pre-stressed steel bar will improve the quality of the country's domicile and open up enormous market for high strength steel wires and strands.

6 Prospects of the cold processed steel bar

6.1 Historic function of cold processed steel bar

At the founding period of the country, when large scale of economic construction was started, since the economy was backward and the country was in extreme shortage of materials, the steel bar had to be cold drawn to improve strength and reduce the using amount. In 1960s and 70s the cold drawn steel wires were used as pre-stressed orifice plate to save steel bars and prevent cracks in stringboard. Since the 1990s, the cold ribbed steel bars and cold twisted bars have been developed, the application fields have expanded to site casting structure where they are used as non pre-stressed steel bar. Though cold processed steel bars have bad ductility and unstable quality, nevertheless if abiding by the relative standards concerning normal designing, constructing and using, they can still meet the necessary safety requirements of the structures. For several scores of years, the constructed buildings as many as billions of square meters are still in use. All those that found in problems are very few. The cold processed steel bars have played a great role in the country's economic construction. This should gain sufficient affirmations.

6.2 Limitation of cold processed steel bar

The design strength of grade I steel bar f_y 210Mpa, uniform elongation $\delta_{gt} \geqslant 20\%$; after being cold processed, the design strength f_y is 360Mpa, and the uniform elongation δ_{gt} is 2%, where the strength is limitedly improved 70%, the ductility loses nearly ten times. At present, when the steel products are in sufficient supply, comprehensive consideration of the influence from strength, ductility and destructive formation have to be made, and small scale production brings unstable quality and low qualification rate, the weakness of cold processed steel bar is even more obvious. Besides, the price advantage of cold processed bar is no more existing. As for non pre-stressed steel bar, its ratio of strength and price is 15% lower than that of grade III steel bar of small diameter; as for pre-stressed steel bar, it is 30% lower than helical ribbed steel bars of medium and high strength. Therefore, cold processed steel bar of low quality and high price will finally be replaced with normal steel bars of good quality and low price that are produced in large scale.

6.3 Prospects of cold processed steel bar

To replace cold processed steel bar completely will take a long time. This is because of the differences of development and technology levels in various parts of the Country, the inertial design convention and traditional procedure; the update of regulations, standard drawings and calculating program needs some time, and there are some influences from the administration authority and market. Cold processed steel bar will be used for a relative long period. Therefore, it is very important to strength management and to stabilize the quality to ensure the structure safety. The following measures are recommended for adoption:

(1) Strengthening quality management, implying production license and strict product inspection system, firmly preventing unqualified products from putting into use in projects.

(2) Eliminating administration interference, stopping blind expansion of production scale; strengthening market management and preventing unqualified cold processed steel bar coming into market.

(3) Control the application fields of cold processed steel bar: revising standard drawing to realize replacement with high efficient pre-stressed bar, be careful in consideration of redistribution of plastic internal force in cold processed bar, using cold processed steel bar only as force-bearing bar in structures like wall, plate or small sized beam, adopting the frame vertical bars, fabricating bars, distributing bars as well as surface layer-used bar in common use.

(4) Improving of the cold processed steel bar itself. As for helical ribbed steel wire of 500 MPa, duo to its low strength, it has reserved better ductility that is more than 3%, and moreover, it has big inscribed circle area and good anchoring performance. It is currently the hopeful form of steel bar. Under condition of market economy, the fate of cold processed steel bar depends on whether it can meet the international ductility

requirements and the ratios between strength and price is acceptable or not. Its future will depend on the competition, not the administrative measures.

7 Development of the relative application technology for steel bar project

7.1 Manufacturing of semi-finished products

When steel bars reach to construction site, they must be cut to length, and bended into hooks; when supplied in coils, they have to be uncoiled and straightened; some are to be welded into meshes. If delivered in deep processed semi-finished products such as cut to length steel bar, rib meshes and frameworks, it may enormously reduce the site construction works to improve factorized degree of construction and to ensure the project quality.

7.2 Connection technologies of steel bars

Apart from lap joint and weld, the connection technologies have rapidly developed in recent years, and there are many types of connections. Optimizing the simple and reliable methods for popularizing have great significance in guaranteeing the reliability of internal force transmission of bar joints and improvements of project quality.

7.3 Anti-corrosion technology

To solve issues like sustainable development and the durability of steel bars, the anti-corrosion technology develops rapidly. Steel bars with epoxy coating have already put into production and relative regulations have been compiled, the application is also started in projects. Anti-corrosion technologies for galvanized steel wire and no-coherence steel strand are being developed and applied in practice.

8 Conclusions

i Concrete structure should have the grade III steel bar of 400 Mpa as the main force-bearing steel bar.

ii Pre-stressed concrete structure should use helical ribbed steel wire and strands with high strength and low relaxation as the main force-bearing steel bar.

iii Small diameter hot rolled steel bar of grade II, III will replace grade I steel bar and cold processed steel bar and will be widely used.

iv Cold processed steel bar is not suitable to be used as pre-stress fabricating, not suitable to consider plasticity design, and can only be used as force-bearing steel bar in small structures like plate and wall as well as for auxiliary fabrication

v As for cold processed steel bar, management should be strengthened, quality should be controlled to meet standard requirements; the relative market also needs to be regulated; the performance, especially the ductility should be improved. It has to be optimized or eliminated. All in all, the future of cold processed steel bar depends on the market competition.

vi Try to realize deep processing of steel bar, develop technology in relation with projects.