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Relationship and comparison exploration between post-installed and pre-embedded rebar

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Abstract

Based on the design requirements of pre-embedded and post-installed rebar anchorage in the current concrete structure design code and concrete structure reinforcement design code, and the anchoring mechanism and influencing factors of pre-embedded and post-installed rebar are compared and analyzed, The anchorage strength and anchorage length of the two types of anchorage are calculated and analyzed. The results show that the design value of bond strength of post-installed rebarr is larger than that of pre-embedded. The basic anchorage length of the post-installed rebar is smaller than that of the embedded bar, but after considering the influence coefficient, the design anchorage length of the post-installed rebar is higher than that of the embedded bar in the low strength concrete, and the structural requirements of the two are also different.

Keywords

Post-installed rebar; pre-embedded; anchoring mechanism; anchorage length.

1. Introduction

The technology of post-installed rebar is a post anchoring technology which uses the fast and high-strength curing effect of chemical binder to fix the anchor bar on the concrete substrate to achieve the same effect as the embedded steel bar and effectively connect the existing structure and the new structure. In recent years, scholars at home and abroad have done a lot of experimental research and finite element analysis, and have a more comprehensive understanding of the mechanical performance and anchorage mechanism of the structure[1]-[4].The code also gives the relevant provisions of planting reinforcement, but it is only the preliminary research results. There are still doubts about the consistency between the calculation method of post-installed rebar depth and the anchoring mechanism of embedded, which brings inconvenience to the practical engineering application. Based on the current "Code for design of concrete structures GB 50010-2010" (abbreviated as GB 50010) [5]and "Code for design of reinforcement of concrete structures GB 50367-2013" (abbreviated as GB 50367)[6], this paper makes a comparative analysis of the embedded reinforcement and embedded anchorage[7].

2. Anchorage mechanism comparison

2.1. Anchorage principle of pre-embedded

The mutual bonding between reinforcement and concrete is mainly composed of chemical bonding force, friction resistance, and mechanical biting force[7]-[10]. Mechanical bite force plays a leading role. The bonding effect of the circular steel bar is mainly the first two forces, and the bonding effect of the deformed steel bar mainly comes from the mechanical occlusions between the concrete and the convex ribs of the steel bar surface.[11] This interaction makes

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the deformed steel bar exert a large oblique force on the surrounding concrete. When the radial component perpendicular to the direction of the steel bar is large enough, an internal radial crack will be formed. Because the concrete strength between the surface ribs of the reinforcement can not be fully utilized, the concrete located at the top corner of the ribs of the reinforcement will crack, or be crushed. It is only when this type of concrete is cut and the maximum bond strength is reached that the steel bars in the concrete will slide and fail. This mechanical occlusion is the most effective and reliable bond between the deformed steel bar and concrete, and can give full play to the strength of the steel bar in the concrete structure[12].

These three kinds of bonding effects are closely related to the roughness and corrosion degree of the steel bar surface, so it is difficult to measure one of them and divide them strictly in the process of test. Moreover, the bonding effect of each part of reinforcement will also change with the change of load and slip at different stress stages[13].

2.2. Anchorage mechanism of post-installed rebar

Different from embedded anchorage, chemical planting-bars transfer loads. The anchorage performance between plant-bars and concrete is realized by structural adhesive between steel bars and concrete. When the plant-bar anchorage system is under stress, the force transmission depends on the chemical bonding and mechanical locking of the structural adhesive. When the plant-bar reaches a certain buried depth, the rear anchor bar will have a strong pullout resistance and little slip, so as to ensure the anchorage strength and endurance.

Due to more anchoring glue participating in the force in the planting bar, its failure type is more complex. According to a lot of test analysis, there are five forms as follows, shown in Fig. 1.

Cone destruction. Basically belongs to the brittle failure, the buried depth of the general planting bar is short, the bond stress of the two contact surfaces and the tensile strength of the steel bar can not be fully played;

Damage of concrete-glue interface. is the bond failure, reinforcement and colloid are pulled out together;

Reinforcement-glue interface damage. is the bond failure, glue and reinforcement reinforcement bonding force is small, only the reinforcement is pulled out;

Mixing interface failure. The interface of concrete and glue is destroyed near the force end, and the interface of steel bar and glue is destroyed far;

Bar pulling. Generally planting bars buried deep is very long, the steel bar tensile yield or pull off.

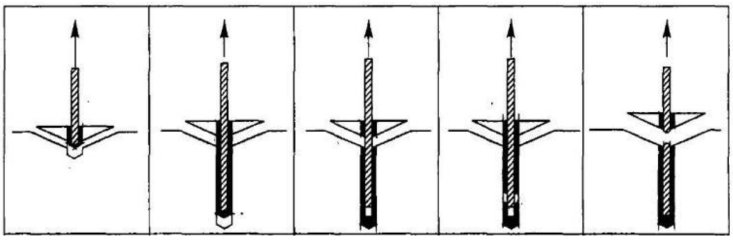

Fig. 1.Five Failure Modes of post-installed rebar Drawing

3. Anchorage strength of pre-embedded and planting-bar anchorage

In GB50010, a large number of pre-embedding experiments were carried out to determine the main factors affecting bond anchorage strength, including tensile strength of concrete, stirrup ratio, relative anchorage length, protective layer thickness, etc., and a formula for calculating the test value of bond anchorage strength under the ultimate state was established by statistical analysis Eq. (1).[14]

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Considering that the ultimate state of anchorage bearing capacity is the yield of reinforcement and anchorage failure occurs simultaneously, the ultimate state equation of anchorage can be obtained from the equilibrium condition as follows Eq. (2) and (3).

$$f_{bm}^{CI} = (0.82 + 0.9d/l_m)(1.6 + 0.7c/d + 20\rho_{sv})f_{tm} \tag{1}$$

$$\pi d l_{\mathrm{ab}} f_{\mathrm{bd}}^{\mathrm{CI}} = (\pi/4)d^2 f_{\mathrm{y}} \tag{2}$$

$$4(l/d)f_{\mathrm{bd}}^{\mathrm{CI}} = f_{\mathrm{y}} \tag{3}$$

Determine the mean value, mean square error and distribution type of each coefficient in the above formula, and determine the design value of pre-embedded basic anchorage strength through systematic bond anchorage test study and reliable complex analysis of all kinds of steel bars Eq. (4).

$$f_{\mathrm{bd}}^{\mathrm{CI}} = f_{\mathrm{t}}/(4\alpha) = 1.79 f_{\mathrm{t}} \tag{4}$$

Where α is the shape coefficient of the anchorage reinforcement, and its value for ribbed reinforcement is 0.14, The values of $f_{\mathrm{bd}}^{\mathrm{CI}}$ in Table 1.

However, GB50367 does not specify the calculation formula for the specific anchorage strength of the planting bars, but gives the fixed value. It can be seen from the comparison between pre-embedded and post-installed rebar , that the design value of the bond strength of the planting-bar $f_{\mathrm{bd}}^{\mathrm{PI}}$ is larger than that of the embedded bar $f_{\mathrm{bd}}^{\mathrm{CI}}$.

Table 1.Bond strength of cast-in rebar

Bond strength	Strength grade of base material concrete								
	C20	C25	C30	C40	C60	C65	C70	C75	C80
$f_{\mathrm{bd}}^{\mathrm{CI}}$	2.0	2.3	2.6	2.8	3.1	3.7	3.7	3.8	3.9

4. Anchor length comparison

4.1. Basic anchorage length

In GB 50010, the reliability of anchoring force is guaranteed by force balance conditions and a large number of experimental data combined with reliability analysis. The calculation formula of the basic anchoring length of pre-embedded $\mathrm{l}_{\mathrm{bd}}^{\mathrm{CI}}$ is obtained as Eq. (5):

$$\mathrm{l}_{\mathrm{bd}}^{\mathrm{CI}} = \alpha \frac{\mathrm{f_y}}{\mathrm{f_t}} \mathrm{d} = 0.14 \frac{\mathrm{f_y}}{\mathrm{f_t}} \mathrm{d} \tag{5}$$

In GB50367, according to the ultimate state condition that the failure strength of concrete cone damage and bond damage is equal to the tensile strength of reinforcement, the reliability analysis is carried out, and the calculation formula of the basic anchorage length of the planted reinforcement $\mathrm{l}_{\mathrm{bd}}^{\mathrm{PI}}$ is obtained as Eq. (6):

$$\mathrm{l}_{\mathrm{bd}}^{\mathrm{PI}} = 0.2 \frac{\mathrm{f_y}}{\mathrm{f}_{\mathrm{bd}}^{\mathrm{PI}}} \mathrm{d} \tag{6}$$

When concrete with strength grade of C20~C80 is inserted and HRB 400 steel bar is used, the basic anchoring length of the planting bar and the pre-embedded anchoring length are calculated $\mathrm{l}_{\mathrm{ab}}^{\mathrm{PI}}/\mathrm{l}_{\mathrm{ab}}^{\mathrm{CI}}$, as shown in Table 2 , and make the comparison diagram Fig. 2.

Table 2.Ratio of anchor length l_{ab}^{PI}/l_{ab}^{CI}

Tectonic conditions	Strength grade of base material concrete								
	C20	C25	C30	C40	C60	C65	C70	C75	C80
$s_1 \geq 5d; s_2 \geq 2.5d$	0.68	0.67	0.55	0.56	0.54	0.65	0.66	0.68	0.69
$s_1 \geq 6d; s_2 \geq 3d$	0.68	0.67	0.51	0.50	0.49	0.58	0.60	0.61	0.62
$s_1 \geq 7d; s_2 \geq 3.5d$	0.68	0.67	0.45	0.45	0.44	0.53	0.54	0.56	0.57

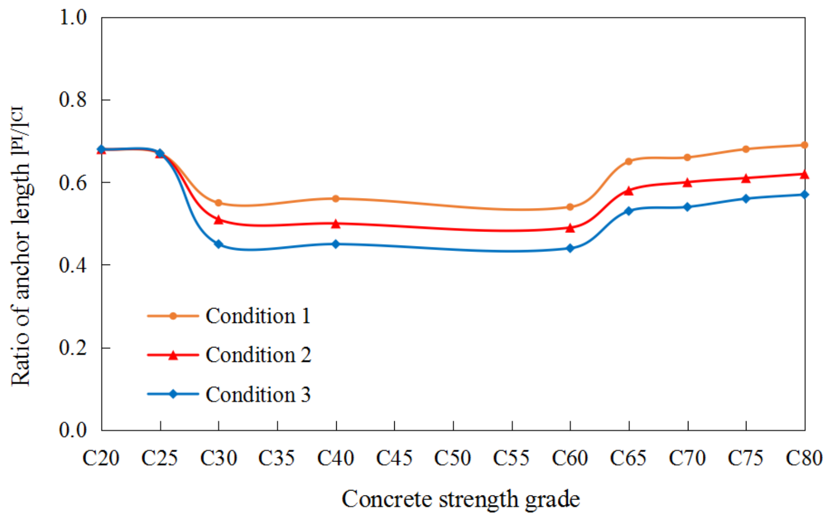

Fig. 2. Ratio of anchor length

It can be seen from Table 2 and Fig. 2 that the basic anchorage depth of the planting bars is smaller than that of the pre-embedded , and is between 0.46 and 0.7.

4.2. Design value of anchorage length

4.2.1. Computational formula

GB50010 stipulates that in engineering practice, according to different anchorage conditions, the anchor length l_{ab} should be revised, calculated according to the Eq. (7), and the correction coefficient can be obtained according to the Table 5, and can be multiplied. And in any case, in order to ensure reliability, the anchorage length of the tensile reinforcement should not be less than the minimum, its value should <0.6 l_{ab} and 200mm.

In GB50367, the revised anchorage length of the planting bars is calculated according to the Eq. (8). The correction coefficient to ensure the displacement ductility in the earthquake-resistant area meets the design requirements is considered. At the same time, the calculation coefficient to prevent concrete splitting and the correction coefficient to influence the tensile performance of the planting bars are introduced according to the relevant guidelines of American ACI [15] and European standard EC2.

$$l_a^{CI} = \zeta_a l_{ab}^{CI} = 0.14\zeta_a \frac{f_y}{f_t} d \tag{7}$$

$$l_a^{PI} \geq \psi_N \psi_{ae} l_{ab}^{PI} = 0.2\alpha_{spt}\psi_N \psi_{ae} \frac{f_y}{f_{bd}^{PI}} d \tag{8}$$

4.2.2. Correction coefficient

The influence factors and values considered in the correction coefficient of embedded and embedded reinforcement anchorage were simply compared, as shown in Table 3.

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Table 3.Comparison of influencing factors

Number	Factor	Pre-embedded	Planting-bar anchorage
1	Thickness of cover（s2)	s2=3d, take 0.80 s2=5d, take 0.70	Splitting effect Between 1.0 ~ 1.25
2	Steel bar diameter	>25mm, take1.10	
3	Stirrup diameter and spacing	Structure regulation	
4	Reinforced coating	Epoxy coated ribbed steel bar 1.25	—
5	Construction operations	Steel bars susceptible to disturbance during construction 1.10	—
6	Reinforcement area	The actual area is larger than the designed area. Take the ratio of the designed area to the actual area (structural members considering seismic fortification and dynamic load are not considered).	—
7	Wet state of hole wall（ψ_{W})	—	≥1.1
8	The stress state（ψ_{br})	—	Cantilever 1.5 Non-cantilever important 1.15 The other 1.0
9	The environment temperature（ψ_{T})	—	T≤60℃, 1.0; 60℃ < T≤80℃, medium temperature resistant adhesive , according to the value specified in the product manual; T >80℃, high temperature resistant adhesive
10	Displacement ductility requirements（Ψ_{ae})	—	1.10 for the 1 and 2 class sites in the 6 degree area and the 7degree area; 1.25 for the 3 and 4 class sites in the 7 degree area and the 8th degree area; When the concrete strength is higher than C30, take 1.00

Comparison between the two results:

(1) Influence of protective layer thickness:

When S_2 =3d for embedded anchorage, the correction coefficient is 0.80; when S_2 =5d, the correction coefficient is 0.70, and the intermediate value is interpolation. The thickness of the protective layer is modified from two aspects of concrete splitting coefficient and bonding strength by planting bar anchorage.

(2) Influence of steel bar diameter:

Compared with the provisions of pre-embedded, the planting bar is considered more carefully. Embedding only stipulates that the reinforcement bar diameter >25mm should be corrected. When the diameter of the planting bar is ≥25mm, the influence of the thickness of the protective layer and the transverse reinforcement shall be considered to adjust.

(3) Stirrup diameter:

For embedded anchorage, it is strictly stipulated that stirrup diameter ≥d/4 should be within the range of anchorage length. However, for planting reinforcement anchorage, when the thickness of protective layer is less than or equal to 30, only stirrup diameter >d/4 should not be corrected. Otherwise, all stirrup diameter should be corrected, and the correction coefficient range is 1.05~1.25.

(4) Construction process

The influence of reinforcement disturbance during construction is considered in the embedding process. The planting bars are modified to the moisture, ambient temperature, stress state and seismic displacement ductility of the hole.

4.2.3. Comparative analysis of anchorage length calculation

The numerical relationship between the anchoring length of pre-embedded and post-installed rebar is compared and analyzed according to the calculation formula of anchoring length stipulated in the code. Calculation parameters are shown in Table 4:

Table 4.Calculated parameters

Concrete strength grade	Steel reinforcement	Concrete cover thickness	Transverse reinforcement	Planting bar glue	Planting bar spacing
C20、C25、C30、C40、C60	HRB400 φ20	2.5d，3d，3.5d，5d	φ6@100	A	≥5d

(1) Basic anchorage length comparison

According to the above formula, the relative anchoring lengths l/d of the two anchoring methods are respectively calculated after considering the thickness of the protective layer. The calculation results of the pre-embedded rebar are shown in Table 5 and the post-installed rebar in Table 6, and the comparison diagram is made as shown in the Fig. 3.

Table 5.Relative anchorage length of pre-embedded rebar

	C20	C25	C30	C40	C60
s2=2.5d	45.82	39.69	35.24	29.47	24.71
s2=3d	36.65	31.75	28.20	23.58	19.76
s2=3.5d	35.51	30.76	27.31	22.84	19.15
s2=5d	32.07	27.78	24.67	20.63	17.29

Table 6.Relative anchorage length of post-installed rebar

	C20	C25	C30	C40	C60
s2=2.5d	31.30	26.67	19.46	18.00	16.00
s2=3d	31.30	26.67	18.00	16.00	14.40
s2=3.5d	31.30	26.67	16.00	14.40	13.09
s2=5d	31.30	26.67	16.00	14.40	13.09

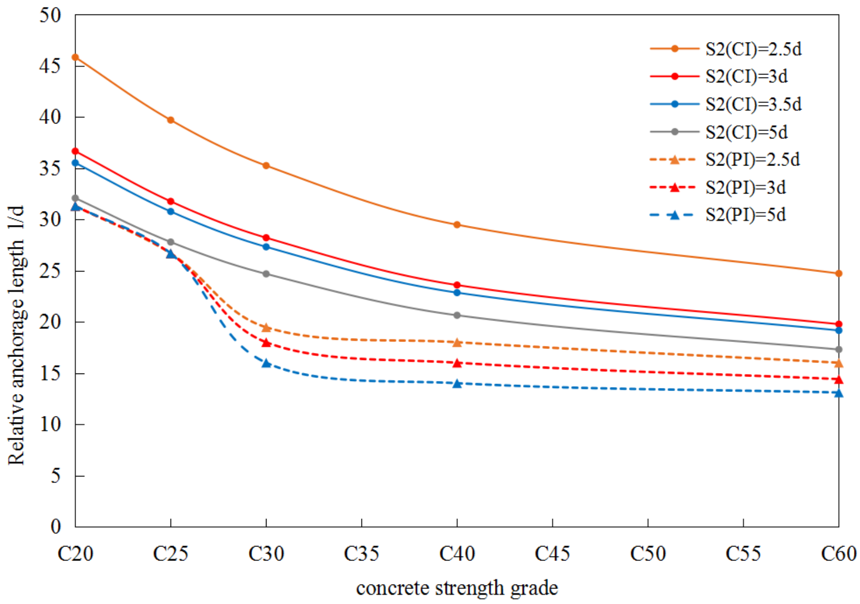

Fig. 3 Relative anchorage length

(2)After considering the correction

After considering the following influence coefficient, the post-installed rebar was compared with the pre-embedded again, as shown in Table 7 and Fig. 4.

Influence parameters: influence coefficient of hole wall moistur $\psi_W = 1.1$; Temperature influence coefficient $\psi_T = 1.0$ (T≤60℃); Construction type coefficient $\psi_{br} = 1.15$ (non-cantilevered important components); Displacement ductility coefficient $\psi_{ae} = 1.1$ (6 degree area and 7 degree area 1, 2 sites).

Table 7.Relative anchorage length of post-installed rebar (after considering the correction)

	C20	C25	C30	C40	C60
s2=2.5d	43.56	37.11	27.08	22.77	20.24
s2=3d	43.56	37.11	25.05	20.24	18.22
s2=3.5d	43.56	37.11	22.26	18.22	16.56
s2=5d	43.56	37.11	22.26	18.22	16.56

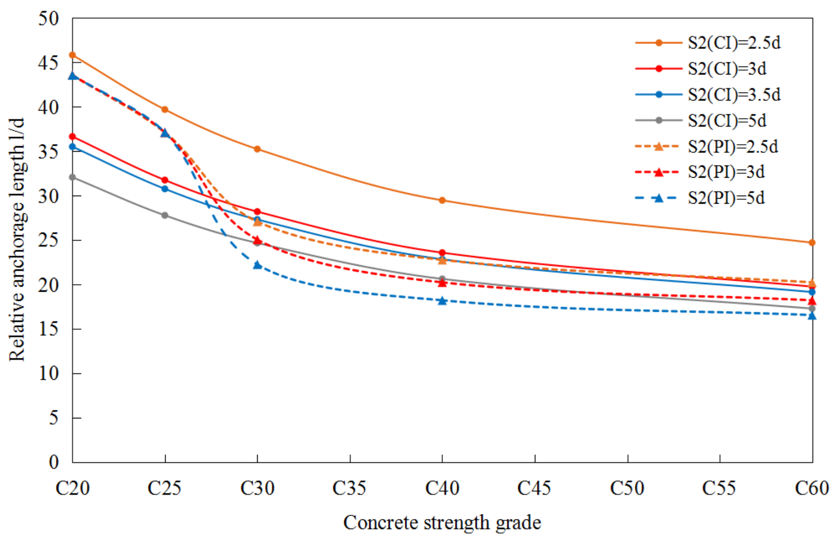

Fig. 4 Relative anchorage length (after considering the correction)

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It can be seen from the Fig.3 that when the embedded depth of the planting bars is not considered the correction factor, the overall buried depth of the planting bars is smaller than that of the pre-embedded bar . Specifically, when the thickness of the protective layer is s_2 =2.5d, the ratio of the design anchorage length of the planting bars to that of the pre-embedded bar l_a^{PI}/l_a^{CI} is 0.55~0.68. When s_2 =3d, l_a^{PI}/l_a^{CI} is 0.64~0.85; When s_2 =3.5d, l_a^{PI}/l_a^{CI} is 0.59~0.88; When s_2 =5d, l_a^{PI}/l_a^{CI} is 0.65~0.98.

It can be seen from the figure below that the buried depth of the planting bars has been improved after considering the correction factor. Specifically, when s_2 =2.5d, l_a^{PI}/l_a^{CI} is 0.77~0.95; When $s_2 \geq$ 3d and the concrete grade is less than C30, the buried depth of the planting bars exceeds the buried depth of the pre-embedded bars and l_a^{PI}/l_a^{CI} is 1.17~1.36. When the concrete strength grade is not less than C30 and the protective layer thickness s_2 = 3d, l_a^{PI}/l_a^{CI} is 0.86~0.92; When s_2 =3.5d, l_a^{PI}/l_a^{CI} is 0.80~0.86; When s_2 =5d, l_a^{PI}/l_a^{CI} is 0.88~0.96. Closer to pre-embedded anchorage length than before correction.

5. Conclusions and Suggestions

1)Pre-embedded anchoring mechanism of planting bar and there is a certain difference, much compared with embedded anchor bar and anchor adhesive, the influence factors damage form is more complex and diverse, planting-bar, when high adhesive strength is not enough, could undermine the surface occurred in rebar and anchor adhesive interface, the bond strength f_{bd} was not related to the concrete itself, but related to the performance of the adhesive. Therefore, the calculation of f_{bd} in the European standard only considers the influence of concrete itself, and whether it is accurate to directly apply it to the planting bar needs to be further explored.

2)Compared with the domestic GB50010 embedded anchoring code and GB50367 plantbar anchoring code, it can be seen that plantbar does not give the specific calculation formula of f_{bd} , but gives the corresponding fixed value based on the comprehensive consideration of the performance and structural requirements of the glue, and there are many unreasonable problems in the value. It can be found that the design value of the bond shear strength of the planting-bars f_{bd}^{PI} is larger than that of the embedded barf_{bd}^{CI}.

3)After the calculation parameters of a certain planting-bar is shown as the basic anchorage length than embedded basic anchorage length of small, after considering the influence of a series of parameters, planting-bar anchorage length is improved, even more than the embedded in low strength concrete anchorage length, but as the concrete strength grade, embedded anchor length is still higher than planting bar length, For important non-cantilevered components is unreasonable, it is suggested to increase the anchorage length of the planting bars.

4)In terms of the structural requirements, it is stipulated that the spacing of the planting bars should not be less than 5d, and the influence of the spacing of steel bars is not considered in the pre-embedded ; When the thickness of the protective layer is less than 3d, it is not corrected; when the thickness ≥3d, it is corrected to 0.8, which is quite abrupt.

5)The thickness of the protective layer is also different. For the embedded reinforcement, it can be very small according to the environmental category, such as 20mm, 25mm. But the thickness of the protective layer should not be less than 50mm, and should not be less than 100mm, and should be ≥ 5d.

To sum up, there are still many differences between the pre-embedded bar and post-installed rebar specification. Based on the European research ideas, the f_{bd} of pre-embedded bar is transformed into the post-installed rebar anchorage f_{bd} . Whether it can be used for reference

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in our country, we still need to do relevant experiments to explore and further comparative analysis.

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