Comparison of retrofit failure to pull out single anchor of plain steel and deformed cast inplace and post installed chemical epoxy methods

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Abstract. One of the anchor functions is to connect the construction steel joint to the concrete to transfer the tensile force of steel to concrete. The research aimed to compare the theoretical and experimental adhesive stress and the pullout capacity of plain steel single anchors and deformed cast in place and retrofit post-installed chemical epoxy sika anchor fix-2. The experimental result of the cast in place method of the plain steel anchors to the theoretical increase by 3.657% and deformed steel anchor increased by 50.13%; retrofit post-installed chemical epoxy sika anchor fix-2 method of plain steel to the theoretical increased by 23.29% and deformed steel anchor increased 63.69% and plain steel anchor method and retrofit post-installed chemical epoxy sika anchor fix-2 to the cast in place increased by 18.404% and steel anchor deform increased by 8.905%. Therefore, retrofit post-installed chemical epoxy sika anchor fix-2 plain anchor and deformed steel anchor give better results than cast in place theory so that the basis for the planning can be used as the basis for retrofit post-installed chemical epoxy sika anchor fix-2 while overall, deformed steel anchor is still better than plain steel anchor.

1. Introduction
The relation between the column and the foundation (based plate) is designed by limitations due to overload, the anchor can fail to pull out so it must be retrofitted by chemical epoxy injection [1,2]. According to the installation method, the anchor is divided into two [3,4]. Anchor cast in place are anchors installed before the concrete is cast and an anchor post-installed are anchors installed on hardened concrete by drilling the concrete and chemical epoxy injection to plant new anchor [5]. In the market, there are plain and deformed steel reinforcement that can be formed into anchors to be used as a retrofit post-installed chemical epoxy [6]. Based on the background of the problem, there has not been found a research journal on Comparison of Retrofit Failure to Pullout Plain Steel Single Anchor and Deform Method Inplace and Post Installed Chemical Epoxy [7-11]. Pullout failure single anchor is done by testing the pullout strength of a plain steel single anchor and deform on anchor diameter 12mm effective planting depth (h_eff) 110 mm with a single anchor distance to the edge of the concrete cylinder less than 1.5 h_eff or 75 mm less than 165 mm. The test result will provide an overview of the theoretical adhesive stress and experiment and plain steel single anchor failure capacity and deformed anchor cast in place method and retrofit post-installed chemical epoxy sika anchor fix-2.
2. Methodology

2.1 Research Methodology
The capacity of single anchor failure is carried out by testing the pullout strength of plain steel anchor and deformed on effective planting depth \( h_{ef} \) 110 mm with a single anchor distance to the edge of the concrete cylinder 75 mm < 165 mm (less than 1.5 \( h_{ef} \)) according to minimum requirements on SNI 2847:2013 with anchor cast in place installation method and retrofit post-installed chemical epoxy sika anchor fix-2.

2.2 Materials
Materials needed in research include 1). Concrete cylinder 25 MPa; 2). Chemical epoxy sika anchor fix-2; 3). Plain steel anchor diameter 12 mm; 4). Deformed steel anchor diameter 12 mm

2.3. Test Object
Test objects needed in research are as follows:
1. Anchor tensile test objects were carried out to determine the magnitude of the yield strength \( (f_y) \), ultimate strength \( (f_u) \) plain steel anchor, and deform steel that will be used as test object.
2. Concrete compressive test object using a cylinder with a size of 150 mm x 300 mm as many as 3 pieces
3. Concrete split tensile test object using a concrete cylinder [12] with the size 150 mm x 300 mm as many as 3 pieces
4. Pullout anchor test on concrete cylinder three-cylinder cast in place method and retrofit post-installed chemical epoxy sika anchor fix-2 as many as 3 concrete cylinders.
5. Anchor cast in place test object installed before the concrete is cast
6. Anchor post-installed test object installed when the concrete is 28 days old by making a hole in the concrete using a drill and then the hole is injected by chemical epoxy sika anchor fix-2 then plant the anchor.

2.4 Test Method
Pullout anchor test is carried out after testing the compressive and shear strength of the concrete with using 1). Compression Testing Machine and 2). Universal Testing Machine.

3. Result and Discussion

3.1. Result
Table 1 and Figure 1.a and 1.b theoretically the cast in place steel rupture off plain steel anchor is 64.173 kN greater than plain steel anchor pullout of 13.598 kN and cast in place steel rupture of the deformed anchor is 74.8 kN greater than pullout of 27.867 kN so it can be ascertained that the plain steel anchor and deform fail to pullout.

Table 2 shows the increase in the adhesive stress of deformed steel anchor to plain steel anchor with the theoretical method by 104.937%, Cast in place method by 396.922%, and post-installed chemical epoxy method by 171.866% from the three methods give the result that the deformed steel anchor better dan plain steel anchor. Table 3 shows the increase in the adhesive stress using cast in place to the theoretical method of plain steel anchor increase by 3.657% and deformed steel anchor increase by 50.13%. Comparison of the adhesive stress post-installed chemical epoxy to the plain steel anchor theory increase by 23.29% while the deformed steel anchor increases by 63.69% as given in Table 4, deformed steel anchor gives the result better than plain steel anchor. Comparison of adhesive stress post-installed chemical epoxy to the cast in place plain steel anchor increase by 18.92% while deformed steel anchor increases by 8.905% as shown in Table 5.
Table 1. Theoretical steel rupture capacity (broken anchor), cast in place and post-installed chemical epoxy

| No. | Failure Type                          | Theoretical (kN) | Cast in place (kN) | Post installed (kN) | Failure Type |
|-----|--------------------------------------|------------------|--------------------|---------------------|--------------|
|     |                                       | Theoretical      | Cast in place      | Post installed      |              |
|     |                                       | Plain Deform     | Plain Deform       | Plain Deform       |              |
| 1   | Steel Rupture (Broken anchor)         | 64.173 74.800    | 64.173 74.800      | 64.173 74.800      |              |
| 2   | Pull-out Failure (Npg)                | 13.598 27.867    | 11.112 41.655      | 14.355 45.567      |              |

Table 2. Theoretical adhesive stress of plain and deformed steel anchor cast in place and post-installed chemical epoxy

| Anchor Type | Theoretical MPa | Cast in place MPa | Post-installed epoxy MPa | Increase % |
|-------------|-----------------|-------------------|--------------------------|------------|
| Plain       | 3.281           | 3.404             | 4.045                    | 104.937    |
| Deformed    | 6.724           | 10.095            | 10.994                   | 396.922    |
| Increase %  | 104.937         | 396.922           | 171.866                  |            |

Table 3. Theoretical adhesive stress of plain and deformed steel anchor cast in place

| Anchor Type | Theoretical MPa | Cast in place MPa | Increase % |
|-------------|-----------------|-------------------|------------|
| Plain       | 3.281           | 3.404             | 50.13%     |
| Deformed    | 6.724           | 10.095            |            |

Table 4. Theoretical adhesive stress of plain and deformed steel anchor post-installed chemical epoxy

| Anchor Type | Theoretical MPa | Post installed epoxy MPa | Increase % |
|-------------|-----------------|--------------------------|------------|
| Plain       | 3.281           | 4.045                    | 23.29%     |
| Deformed    | 6.724           | 10.994                   | 63.69%     |
The research result of the three methods shows the significant differentials that deformed steel anchor is better than plain steel anchor. It is caused by the differential surface characteristic between two anchors, that plain steel anchors have plain surface characteristics so the bonding between anchor and concrete relying on an adhesive bond of concrete with anchor surface, while deformed anchors have a threaded surface (deform) so in addition to providing attachment, it also has an interlocking role between deformed anchor grips so a better adhesive strength is obtained than plain anchor, both theoretical and experimental data show that each anchor has described according to its characteristics.

3.2. Discussion

When comparing research result of Sunarmasto’s [13] research, it gives the result of adhesive stress (μ) plain reinforcement cast in place of μ = 3.279 MPa < 3.404 MPa so the comparison between the research result and Sunarmasto’s research result is close to the same while for the deformed reinforcement gives result μ = 6.202 MPa < 10.095 MPa the research provide greater result than Sunarmasto’s research result.

The result of the research on the adhesive stress of deformed steel anchors to the cast in place plain steel anchors by 10.095 MPa > 3.404 MPa increased by 396.56% and for the post-installed chemical epoxy by 10.994 MPa > 4.045 MPa increased by 171.79% the difference between plain steel anchors and deformed steel anchors is due to the characteristics of the deformed steel anchor having the formula used to calculate the adhesive stress of the deformed reinforcing steel which is different from the plain reinforcement steel because of the shape of the surface. Deformed steel can improve the adhesive capacity due to the locking of the two threads and the surrounding concrete. The tension that occurs between two threads is a combination of some tension that is: 1). Adhesive stress resulting from adhesion along the surface reinforcing steel; 2). Surface adhesive tension, and; 3). Adhesive stress acting on the cylindrical concrete surface close to the deformed steel anchor so that the result of the research show the value of the adhesive strength of μ =10.095 is influenced by the three surface tensions of the deformed reinforcement to the concrete.

Retrofit aims to repair anchor failure in the joint caused by various things due to corrosion or broken anchors due to exceeding the maximum capacity. Anchor failure can be retrofitted by chemical epoxy which gives a result that is close to the cast in place. The post-installed method with chemical epoxy can be referenced as a retrofit anchor, both plain and deformed anchor, post-installed chemical epoxy method the result is better than the cast in place theory. One of the anchor functions is to connect the construction steel joint to the concrete to transfer the tensile force of steel to the concrete. The excessive tensile force causes the anchor to pull out of the concrete so that the construction is categorized as failed to pull out. Pullout failure anchor due to excessive tensile force can be retrofitted by chemical epoxy injection into the concrete repair of anchor holes for plant new anchors and the result of retrofit experiments with chemical epoxy showed that deformed anchor and plain anchor better than theoretical calculation and cast in place and in general the deformed anchors are better than plain anchors.

| Table 5. Experimental adhesive stress of plain and deformed steel anchor post-installed chemical epoxy to the cast in place |
|---|
| Anchor Type | Cast inplace MPa | Post installed epoxy MPa | Increase % |
| Plain | 3.404 | 4.045 | 18.92% |
| Deformed | 10.095 | 10.994 | 8.905 |
| Increase % | 396.56% | 171.79% |

One of the anchor functions is to connect the construction steel joint to the concrete to transfer the tensile force of steel to the concrete.
4. Conclusion and Suggestion

4.1. Conclusion
The result of research on deformed steel anchor to the plain steel anchor cast in place by 10.095 MPa > 3.404 MPa and for post chemical epoxy of 10.994 MPa > 4.045 MPa. Theoretically, the capacity of plain steel pullout failure is 13,598 N with the adhesive stress of 3.281 MPa and deformed steel anchor by 27,867 N with the adhesive stress of 6.724 MPa, experimentally, cast in place obtained plain steel anchor 11,112 N with the adhesive stress of 3.404 MPa and deformed steel anchor by 41,655 N, with the adhesive stress of 10.095 MPa. The post-installed chemical epoxy experiment obtained a plain steel anchor capacity of 16,765 N with the adhesive stress of 4.045 MPa and a deformed steel anchor of 45,567 N with the adhesive stress of 10.994 MPa. In percentage, the experiment result of plain steel anchor theoretical method to the cast in place increased by 3.657%; deformed steel anchor increased by 50.13%; plain steel anchor theoretical method to the post-installed chemical epoxy increased by 23.29%, and deformed steel anchor increased by 8.905%. Therefore, the retrofit of post-installed chemical epoxy plain steel anchor and deformed steel gives better results than theory and cast in place while the overall deformed anchor is still better than plain steel.

4.2. Suggestion
1. Prepare the anchor near the hole, make sure the anchor is clean from dust and dirt
2. A borehole and depth 2mm greater than anchor centerline
3. The execution of drilling work is carried out carefully
4. Make sure the chemical epoxy injection is filled into the retrofit hole
5. Anchorage installation immediately after chemical epoxy injection due to the chemical epoxy hardens quickly.

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