A Study on the Applicability of Replacing GI Wires with Plastic Cable in Structural Members

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Abstract: Reinforced concrete has been a popular choice in the construction of structures due to its strength and durability as well as its availability. Basically, concrete is reinforced with steel bar assembly, and GI wires are used to hold the assembly in place. However, the traditional procedure in assembling the steel bars can be tedious and time-consuming especially for a non-skilled worker. This study aims to investigate the possibility of replacing GI wire with commercial plastic cable ties and evaluate its effect on the structural integrity of a reinforced concrete member. The two major factors that shall be focused in this study is the overall strength of the structural member and the time consumed to tie steel bars using both tie materials. Since there is no direct test for tie strength determination in reinforcing steel, the researchers modified the standard method of pull-out strength test for steel bar imbedded in concrete (ASTM C900) in order to get an approximate tie strength. A reinforced concrete column was also tested based on the Standard Compression Test (ASTM C39) to assess the effect of using plastic cable as tie wire. From these tests, the researchers determined that although the strength of the plastic cable is slightly weaker than that of the GI wire in the modified pull-out test, the resulting strength from the compression test of the reinforced concrete column samples is still higher than the requirement stipulated in the 2010 National Structural Code of the Philippines. As for the tying speed of an amateur worker, the time used for tying with plastic cable is almost one-third only of that of the GI wire.

Key Words: plastic cable tie; tie substitute; tie strength; GI wire

1. INTRODUCTION

Nowadays, most of the structures built by engineers anywhere in the world have structural components made of reinforced concrete. This had become a common material used in constructing the structures of today due to its high compressive strength and durability. A reinforced concrete member is first made by assembly of reinforcing steel bars. Steel framings called steel reinforcement are used. Afterwards, concrete is poured into the mold with the steel assembly inside it and is cured for a set amount of days. This steel bar fortification is assembled by tying them with GI Wires, which is the traditional procedure for holding them together.

The primary concern on GI Wires is that these ties cannot be effectively tied by non-skilled workers. Studies to find innovative ways of assembling structural reinforcements have been done by other researchers in the past. As early as 1967, Lawrow invented a plier-like tool for grasping and twisting wires. This tool lessened the difficulty of tying and removed the limitation of the movement that can be made by the wrist. Afterwards, in 1990, McCavey invented an electrically powered wire tying tool that prevented much of fatigue and injuries of workers caused by repetitive moment syndrome.

Aside from inventing tools that eased up tying of GI wires, there are also researchers attempting to find substitutes for the GI wire itself. In 1996, McDevitt proposed the use of plastic harness system to space, tighten, and hold the bars to prevent dislocation due to pouring of concrete. This harness system provided a holder for reinforcing bars oriented in either parallel or perpendicular, moreover, since the material was made of plastic, it is not subjected to rust.

Deformable metal fastener clips or more commonly known as "hog rings", which are generally "U"-shaped members were also possible options for substituting traditional tire wire. Open on one side, the hog ring can be easily placed over two or more adjacent reinforced steel member and then closing the open side. By using hog rings, it is expected to consume less time and cost for the laborers (Nowell, 1997).

However, up until the present, the studies mentioned above were not yet really implemented in actual constructions which show the need of further researching and investigating for alternative materials or methods for tying reinforcing steel bars in concrete.

The primary objective of this study is about replacing these GI Wires with commercial plastic cable ties. Plastic cable ties are normally just used in bundling dangling cables for organization. The main advantage of plastic cable ties is that its installation is as easy as slipping the free end inside the lock, and pulling the free end to tighten it. Moreover, plastic cable ties are unlikely to rust and not prone to cause injuries. Although ties are thought to contribute negligible strength to structural members, the study aims to further investigate this assumption and to quantify these effects.

2. METHODOLOGY

This research focused on the ties used in the fastening of structural members. The resistance of the tie is quantified by through pull-out test (ASTM C900). Some modifications of the pull-out test were done to measure the pull-out resistance of the ties, which is considered as the strength of the ties.

Aside from determining the strength of the tie, its effect on structural member was also investigated. RC column was chosen to be investigated instead of other structural members because volumetric change is more noticeable and columns are usually more exposed to extreme loading cases. The tendency for the bar joint movement is more likely to happen, and thus may exhibit pull-out action. In this manner, the contribution of the tie may be more examined and quantified.

2.1 Pull-out test

Currently, there exists no direct test for determining the strength of ties in reinforcing steel. Thus, the researchers improvised a testing method by modifying the Standard test method for pull-out strength of hardened concrete (ASTM C900) wherein two perpendicular steel bars are tied and placed inside a cylindrical concrete specimen. Another specimen was prepared following the standard ASTM procedure and was treated as the reference value. The equation below was used to determine the strength of the ties.

$$P_{tie} = P_{mod} - P_{std} \qquad \text{(Eq. 1)}$$

where:
P_{tie} = tensile strength of the tie
P_{mod} = tensile stress of the modified pull-out test
P_{std} = tensile stress of the standard pull-out test,

To evaluate the strength of the ties, the following steps were followed as procedure in preparing the test specimens for the modified pull-out test:

1. Two steel bars were joined together into a cross manner, as shown in figures 1 and 2 showing how the two steel bars were tied.


Fig. 1. Tying with GI wire


Fig. 2. Tying with plastic cable

2. The two steel bars were secured together by tying GI wires or plastic cable ties at the intersection of the steel bars with either "Double Snap" or "Saddle" as shown in Figure 3. The time for tying was recorded.

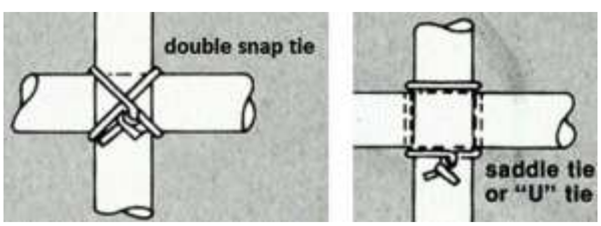


Fig. 3. Double snap tie (Left) and saddle tie (right)

3. The longer vertical steel bar, which is the one that will be pulled-out, was positioned at the center of the cross section of the mold before the concrete mix was poured as shown in Figure 4..

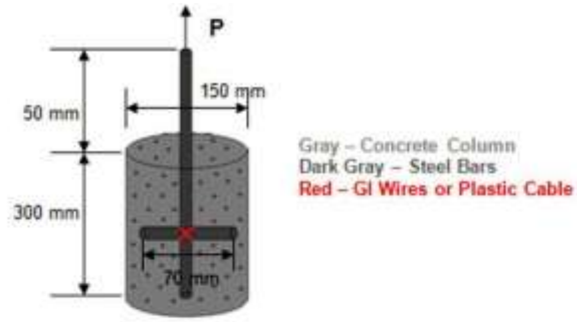


Fig. 4. Test specimen with tie for pull-out test

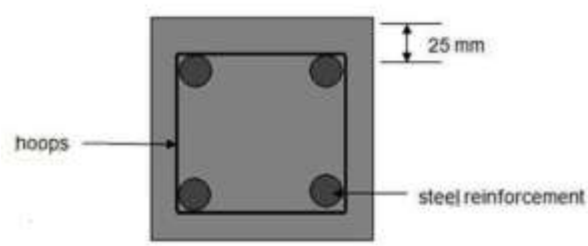
2.2 Compression test of RC column

The performance of RC column was tested following the procedure for Standard Compression Test (ASTM C39). The RC column specimens were tested to failure in order to determine the difference in the performance of specimens tied with GI wires and specimens tied with plastic cable ties.

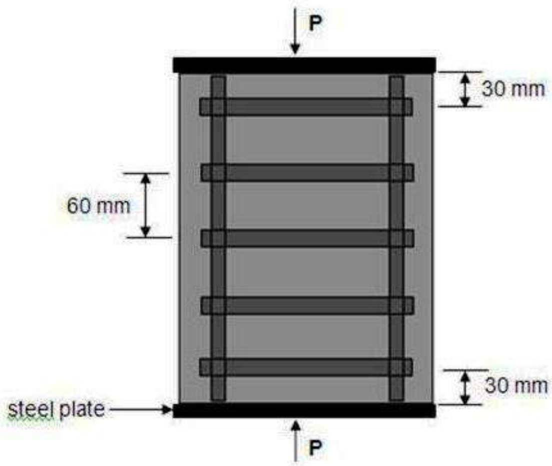
The details of the construction of the RC column specimens are enumerated below.

1. The researchers prepared rectangular molds having a cross section of 150mm x 150mm with a height of 300mm.
2. 4 pieces of 10mm-diameter steel bars with a length of 300mm were assembled to make the concrete column's main reinforcement. An allowance of 25mm serves as the concrete cover.
3. 10mm-diameter steel bars were used as hoops with a spacing of 60mm on center and a 30mm on center clearance on both ends.
4. The two different types of material were used in tying the reinforcing bars of the two column samples: GI wires and plastic cable ties.

The construction details of the finished product (specimens) are shown in Figure 5.



Cross-section



Side view (Elevation)

Fig. 5. Details of RC column specimens

3. RESULTS AND DISCUSSION

The effect of tie is obtained by subtracting the average of the peak pull-out forces of the controlled or standard (ST) specimens from the peak pull-out forces of the specimens with ties. The naming of specimens was derived by following the sequence of the factors considered: material of tie – tying technique – diameter of steel bar – width of plastic cable tie. ST stands for standard pullout specimen which doesn't have a transverse bar and a tie; GI stands for galvanized iron; while PC stands for plastic cable. SN stands for double snap while SA stands for saddle. The diameter of the steel bars and width of plastic cable ties are measured in millimeters. For the GI specimens, only size #14 was used.

3.1 Experiment results

The "effect of tie" was obtained by calculating the difference between peak pull-out force of the specimen and the average peak pull-out force of the ST samples. Its positive value implies that the presence of ties did contribute to the structural strength. The increase in strength based on the specimen without ties (ST-12), expressed as percentage, is shown in Table 1.

Table 1. Percentage increase in strength

Specimen Name	Peak Force (kN)	% Strength Increase in Due to Tie
GI-SN-12	60.67	19.74
GI-SA-12	57.33	13.16
PC-SN-12-8	57.00	12.50
PC-SA-12-8	56.67	11.84
PC-SA-12-6	53.67	5.92
PC-SN-12-6	52.33	3.29
ST-12	50.67	-------

Table 2 shows the results from the compressive strength test of two reinforced concrete columns. One of the columns used the traditional GI wire in tying the stirrups to the longitudinal reinforcements while the other used plastic cable tie.

Table 2. Compression test results of RC column

	Peak Force (kN)
GI column	403.96
PC column	384.33

The values obtained from the two tests were observed to be larger than the theoretical value, which is 364.37kN and obtained based on the strength of steel and concrete. The yield strength and ultimate strength of the steel bars are 304.46 MPa and 486.31 MPa respectively, while the compresive strength of concrete is 11.85 MPa.

Table 3 shows the average tying time of each material in seconds. This shows that the time required for tying Plastic Cable is one-third of that of GI wire.

Table 3. Average tying time

	Average Tying Time(seconds)
GI Wire	90
Plastic Cable Tie	30

3.2 Statistical Analysis

To give more in-depth meaning of the experiment results, statistical analysis was conducted. The statistical analyses are both descriptive and inferential. The software Statistical

Package for the Social Sciences (SPSS) was used in applying statistical treatment to the data results. The ANOVA test (Analysis of Variance) is used to determine the impact independent variables have on the dependent variable in a regression analysis.

The hypothesis test for analysis of variance for *g* populations is as follows:

$H_0 : \mu_1 = \mu_2 = ... = \mu_g$

H_a : At least two averages are not equal.

The Null hypothesis, H_0, is rejected when the P-value (Statistical Significance) is lesser than the given alpha-level of significance.

Table 4. Descriptive analysis of peak pull-out forces

Specimen Name	Ave (kN)	Std Dev	U.B. (kN)	L.B. (kN)	Min (kN)	Max (kN)
ST-12	50.7	2.1	45.5	55.8	49	53
GI-SA-12	57.3	1.5	53.5	61.1	56	59
GI-SN-12	60.7	1.5	56.9	64.5	59	62
PC-SA-12-6	53.7	1.5	49.9	57.5	52	55
PC-SN-12-8	56.7	2.5	50.4	62.9	54	59
PC-SN-12-6	52.3	1.5	48.5	56.1	51	54
PC-SN-12-8	57.0	2.0	52.0	62.0	55	59

The above table (Table 4) shows the descriptive analysis of Peak Force (kN) in different types of specimens used. There were 3 specimens for each type of specimen. The upper bound (U.B.) and lower bound (L.B.) values at the 95% confidence level prediction are shown. For example, for ST-12, peak pull-out force's average value lies between the interval of 45.5 kN and 55.8 kN. The experiment resulted with a minimum peak pull-out force of 49 kN and a maximum of 53 kN. In general, the test results are within the 95% confidence level.

Table 5 shows the result of the analysis of variance for the peak pull-out forces for the different types of specimens. The test is done at the 0.05 level of significance. Since the computed P-value = 0.00 is less than 0.05, it can be concluded that the averages of the different specimens differ from each other.

Table 5. Analysis of variance of peak pull-out force

Specimen Name	Sum of Squares	Df	Mean Square	F	P-Value
Between Groups	211.24	6	35.21	10.27	0.000
Within Groups	48.00	14	3.43		
Total	259.24	20			

The Duncan's Multiple Range Test (DMRT) in Table 6 shows the comparison between the specimens. The values shown in the DMRT table indicate that the sets of values in a group have no significant difference since the yielded P-Value is greater than 5%. Upon analysis of the groups, it can be concluded that plastic cable ties with 6mm or less width have no significant contribution to the strength of the specimen.

Table 6. Duncan's multiple range test result

Specimen Name	**N**	**Subset for alpha = 0.05**			
		1	2	3	4
ST-12	3	50.66			
PC-SN-12-6	3	52.33			
PC-SA-12-6	3	53.66	53.66		
PC-SA-12-8	3		56.66	56.66	
PC-SN-12-8	3		57.00	57.00	
GI-SA-12	3			57.33	
GI-SN-12	3				60.66
P-Value		.080	.054	.682	1.000

The findings shown in groups 1 and 2 indicate that tying techniques of Plastic cable ties does not affect the strength. Similar to the values shown in group 1, the P-value is greater than 5% as well. This implies that tying techniques have little or no noteworthy effect to the strength of the specimen. Group 2 also shows that the width of the plastic cable tie does not affect the strength. Comparing groups 3 and 4 in the DMRT table, it can be observed that tying techniques of GI wires do affect its strength. Upon comparing the 4 groups, it can be concluded that there is a significant difference in terms of strength based on the material of the tie, which is the GI wire and the plastic cable tie.

Table 7. Result of T-test

	Average	Std. Dev	n
Control	209.45	37.99	4
Experiment	378.90	13.275	2

t = 2.63
P-Value = 0.029

H_0: There is no significant difference between the control group and experimental group

H_1: There is a significant difference between the control group and experimental group

Since the P-Value = 0.029 < 0.05, we reject the null hypothesis of no significant difference between the two groups (control/experimental) and conclude that the compressive strength of the RC column is greater than the results of the concrete compressive strength. Focusing on the difference between the values of the two different RC Column (GI and PC), it can be deduced that this difference in value is significant mainly because two different materials were used as ties which is greatly supported by the results of the previous test.

4. CONCLUSIONS

The specimens that were subjected to the modified pull-out test displayed no negative effects whether the material, tying technique and dimensions of the tie was changed as compared to one without a tie. The same test also showed that GI wires specimens yielded a higher pull-out force as compared to that of the plastic cable Tie specimens, but only with a difference of 6.0%. These test results also undertook the Duncan Multiple Range Test that revealed that although the tying technique does affect the pull-out strength of the GI wire ties, it doesn't hold the same for the Plastic Cable Ties.

A batch of reinforced concrete specimens which were designed to experience the compression test gave results that indicated GI wires having a slightly higher peak force than that of the plastic cable tie [GI wire (403.96 kN) | Plastic cable tie (384.33 kN)]. These values were also observed to be larger than the theoretical value, 364.37kN. In constructing these specimens, it was observed that the specimens using G.I wires as ties took at least three times longer to assemble than that of the plastic cable ties, for someone with no experience.

The study on using ties made out of plastic cables revealed that although there is no negative effects in using them, since computing for the strength of a structural member does not take into account the ties, it contributes lesser strength as compared to GI wires. And so for those who want to pursue further studies the researchers recommend the following:

The calculation of the bond strength between the concrete and the steel bar according to the formula given in NSCP may yield a lower value as compared to the actual. And so one must be extra careful to avoid an event where the steel bar yields before the tie otherwise the experiment will be unsuccessful. This can be avoided by decreasing the bond strength by using a smaller diameter or higher grade steel bar or lessening the embedment length.

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