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Axial Capacity of Corrosion-Damaged Circular Columns Wrapped with FRP Composites

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Abstract: This Paper described an experimental study that evaluate the axial capacity of circle column damaged due to chlorination. Fiber-reinforced composite sheets are ideal products to be used as jacketing systems for under designed or damaged reinforced concrete columns that could benefit from confinement of the concrete core. This technology has found two different fields of application in repair and strengthening of existing reinforced concrete columns and bridge piers: 1. Repair and upgrading for earthquake resistance; and 2. Repair of corrosion-damaged members where the transverse and even the longitudinal reinforcement are no longer dependable. The process called half-cell oxidation reaction or response anodic reaction is use to create chlorination process in lab and took result. The result shows that On the average to discuss it clear that concrete after corrosion losses its strength up to an average 23% and after repaired by CFRP it overall strength increase to 51%. In which 23% gain and 23% additional strengthening. It is recommended that jacketing with different material such as fiber-reinforced plastic (FRP) products or composite wraps in lieu of conventional steel (Bars) jackets is more popular method of strengthening bridge piers and columns against seismic resistance and it is useful.
Keywords: CFRP, corrosion-damaged, half-cell oxidation reaction, longitudinal reinforcement

1. Introduction

The serviceability index of reinforced concrete bridges exposed either to sea environment or too strict climatic circumstances (for deicing salts are used for over the year) is frequently limited by early decomposition of significant components, due to reinforcement corrosion such members like deck and pier,

Therefore, for successful repair of these structures there are researches are undergoing for developing practical and economical methods. the main research objected in the current bridge engineer field is to regain the integrity of the structure and enhance the useful life of the structures. When the repair work of chlorine damaged structure starts, there are major hurdles as the transportation structure like bridges and parking areas closed for safety, because repair process needs of shoring the members. sandblasting is used for partial removal of loose rust from the spoiled concrete form the effected part, fill the affected area with inert or low permeability concrete. Many researches argue that is labor intensive procedure and it is not durable. In the start, newly applied patch concrete has zero concentration of chlorides and as the time passes a negative chloride potential difference raises and reverse chloride concentration gradient between damaged and new concrete established, then chlorides ions start flow to newly place patch of concrete which again exposed to the chlorination process due to which again patch / conventual repair is required. The jacketing or confinement method instead of conventional method of repaired stop the volume expansion of concrete and provide long solution to this problem and reduces the chance of brittle failure as concrete expansion is stopped.

The main purpose of the jacketing of reinforcement or FRP confinement in old/conventional concrete is that its application controls the volume expansion due to corrosion product (rust) "the volume expansion is the main cause of failure in the chlorination damaged concrete as rust produce frown reinforcement is the stable form of iron ore which required more space which leads to expansion"

The confinement by fiber reinforced polymer is now gaining rapid popularity because of its superiority over conventional methods. The benefits of using fiber reinforced polymer for strengthening and repairing are high strength to weight ratio, high corrosion resistance, easy for installation and relatively lower cost of maintenance. The previous research demonstrated the effectiveness of FRP for circular concrete cylinders.

Very limited research has been conducted for repair of corrosion damaged structures elements in Pakistan this research work will provide better platform to promote these type of research as there are many concrete structures in Pakistan which are damaged by the chlorination and Pakistan have all type of weather and climate condition in each day of year as sea (Karachi) to hilly snow/ice area (northern side). And many salt range bridges

2. Literature Review

In the modern era new technique for repair of Concrete structure damages due to harsh environment conditioning and other major deterioration process like Alkali Silica reaction, sulphate attack, chlorination and fire damages which mainly causes to damage concrete steel bound and stiffness of the concrete members and mainly load transferring joints. There are many conventional repairing techniques, repaired structure member by these technique shows that these methods are now outdated and more labor and costly intensive and cannot provide longer resistance and again structure start to deteriorate. as a result, extraordinary modern repair required, which is based on the same members which is become very common. Also lead to a huge repair costs, so there are the growing need to solve innovative reform in repair that are strong, economical, and most importantly provide more resistant to corrosion.

As fiber reinforced polymers (FRPs) and advanced composite materials, more specifically, a promising way to repair the corroded structures using these materials as new technologies emerge. This increases tensile strength and well-known prison wrap or cover members. However, the corrosion damage to columns in recent years has been viewed seriously and confinement with FRP is solution. FRP composite sheets were prepared are perfect products to use as jacketing the worse reinforced concrete columns system that could benefit for under design columns to also gain more strength. This technology used on reinforced concrete bridge columns and found two different areas of application in the strengthening of existing piers:

Upgradation of structural members to provide resistance against earthquake (Retrofitting).

Repair of corrosion damaged structural members, where reinforcement is no longer reliable.

Second option is more reliable, cheaper and practical option for repair of corroded structure member of the typical old conventional concrete this study is first taken by the Pantazopoulou and Sheikh in the mid-1990s at the University of Toronto, which mainly focus on the two different sample series against the conditioning repair and testing of the samples. After that this study is converted to a research program in 1998 a carried out by the other researcher as well like Bonacci.

The serviceability index of reinforced concrete bridges exposed either to sea environment or too strict climatic circumstances (for deicing salts are used for over the year) is frequently limited by early decomposition of significant components, due to reinforcement corrosion such members like deck and pier. In recent modern era of concrete jacketing with different material such as fiber-reinforced plastic (FRP) products or composite wraps in lieu of conventional steel (Bars) jackets are becoming more popular method of strengthening bridge piers and columns against seismic resistance. The FRP wraps are usually place in a direction so they produce their tensile resistance in the hoop direction. as they are many times stronger than normal steel, if properly fastened/wrapped they can restrict volumetric expansion and induce very large circumference stresses to core concrete of the column. Minimum labor and time is required to apply this repairing technique which is also a big advantage of this method of repair.

Due to corrosion expansion is also take place due to production of corrosion product (rust) which also required space to store that causes damages the concrete. repair with external confinement is a noticeable remedy. FRP wrap is much more useful method then the simple steel bars jacketing as it protects against the outer suitable environment for more corrosion/chlorination.

In this research, the FRP confinement is used as strengthening element as well as repaired/regaining of original strength of the damaged structural members. In preview of above research work at the University of Engineering and Technology Taxila, involving testing under corrosive environments of a series of small cylindrical columns repaired with a Fiber reinforced polymers sheets is carried out.

In recent research, negative comments for the future repair of chlorine damaged concrete structure is passed by the researches which is quoted below state "… carbon-fiber sheet composites should not be used to confine, arrest, or neutralize the effects of corroding reinforcing steel." (Thomas and Kline 1996)".

That comment is true up to the limit that confinement by FRP sheet is the preserve measure against the future acceleration of chlorination process against a local/single member of the structure but not true to the extent that it is not useful technique for repair of chlorine damaged structure.

In above referred review author sated that if we confined the sample with FRP sheets or jacketing system as a restricting shield the chlorination process wont stopped it remain active within the sample which prove that this method is not suitable for repairing/strengthening of chlorine damaged reinforce concrete member.

But it might somewhat hide the potential failure due to chlorination process which is continue with in the sample, after confinement of FRP

There are some points to understand as it defends the above narrated scenario

Due to FRP sheets wraps a barrier is available to stop free oxygen and chlorine from the water which reduces the crate of chlorination process.

FRP wrap confinement also delay the growth of reaction product (rust) which is the indication of termination of chlorination process. As suggested by the many researcher,

FRP wraps also provided enough outer protection against expansion cause by the reaction product (rust).

Many researchers in this field suggested that importance of above mention factor must be taken in account on the overall long-term performance of FRP confinement on the chlorine damaged concrete members before this important repair technique is fired.

The lab experiment work is research project at the University of Engineering and Technology Taxila under the Master degree program.

In research work scale model of the bridge pier is used which is cored and damaged by the electrochemical solution process and for repair purposed wrapped with fiber reinforce polymers sheets and the comparison between axial capacity of the sample is studied

Some key objected is as follow

An electrochemical galvanic cell process in laboratory is used for accelerated corrosion model and corrosion process effect study

Studying the result of corrosion and repair on the mechanical behavior of reinforced concrete columns,

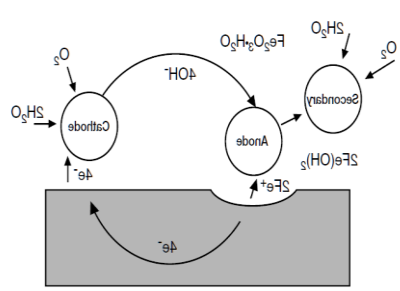
A detail result of axial capacity of the Reference (B) corroded (C) corroded repaired (CR) type column is discussed

Effects on axial capacity by the application of FRP.

2.1 Half-Cell Oxidation Reaction

This process is called half-cell oxidation reaction or response anodic reaction, and represented as follows:

$$2Fe \rightarrow 2Fe^{2+} + 4e^-$$



Electrons remain in the bar, and flow to the location called cathode, which combine with water and oxygen in the concrete and it called the reaction at the cathode causes reduction reaction. A common reaction is maintained neutrality electric reduction, and iron ions migrate through the concrete pore water of the cathodic sites where they accumulate to form hydroxides of iron, or rust:

$$H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

$$2Fe^{2+} + 4OH^- \rightarrow 2Fe(OH)_2$$

This precipitated the initial hydroxide tends to further interact with the oxygen to form higher forms of oxides. The increase in the size of the reaction products which react with more dissolved oxygen leads to internal tensions inside the concrete, which is the main cause of spalling and cracking of the cover of concrete. Corrosion of metals is an integral part of the concrete, which can be greatly reduced by the pouring of concrete crack-free with low permeability concrete cover is sufficient.

3. Experimental program and material properties

Seven cylindrical column specimens (03 no. Reference (Undamaged) “B”, 04 No. Corroded (Damaged) “C” after repaired with CFRP 04 no. Type “C” converted to Corroded Repaired (Damaged Repaired) “CR”) were cast with dimensions 302 mm in diameter by 1200 mm in height and reinforced with three 13M (13M = 12.7 mm nominal diameter) longitudinal steel bars at 12.7 mm cover have Grade 40 (Fig. 3.1).

In past last 20-25 year, back the nominal steel ration for typical bridge design were taken $\rho_s = 1.7\%$ which is confidentially used in simple underpasses and flyovers throughout the Pakistan, the specimen used in the research is 1/3 scale model of typical bridge piers the main steel/ longitudinal reinforce is connected to 12V DC source(Battery) and center bar along center line of test samples bar of 13M is to provide for cathode shown in (Fig. 3.1).

To provide the even condition like 20-25-year old concrete normally used in bridge construction to increase the chlorination rate a low-quality concrete have $w/c = 0.6$ with 28 days’ compressive strength $f_c' = 24\ MPa$ is used.

Fig 3.1: Reinforcement Cage

Fig 3.1: UPVC pipe for casting of sample

3.1 Conditioning to Accelerated Corrosion

In presence of oxygen the iron converted to ferrous Fe^{2+} ions and ferric oxides (Fe^{3+} ions) which is normally called red rust, the corrosion process is start and accelerate as it damaged the surface layer of the reinforcement, it happens due to carbonation or corrosion process and more favor able environment is available for chlorination process. In bridges the main sources of de-passivated of layer is due to absorption of chlorine for the water able due to deicing salts.

With reference to above scenario expensive corrosion process is took place and reaction product occupy more space the steel. Under control environment limited oxygen is available to which generate soft and black water-soluble compound. If the damaged/corroded steel used in structure it produced the reaction product (red rust) which required more space resulting in the cracking in the members

To provide the same environment in lab electrochemical cell process is required which also accelerate the corrosion process as to took the experiment with n the study duration and a systematic study of corrosion process is also possible. For this a 12V DC power source (battery) is used, anode is connected to the 6-Nos main/longitudinal reinforcement bars and cathode is connected to a 13M bar place along the centerline of the sample for an electrochemical cell is established. Samples are placed in a plastic drum in the start of the process the container is filled up to ¾ height with 5% Cl2 solution after one month level reduced to about 600mm container covered with the plastic sheets to provide more humid environment to accelerate the rate of corrosion.

Fig 3.3: Chlorination Setup

Fig 3.4: Current flow value during Chlorination

After simple testing column designated C1, C2, C2 CFRP rapped and converted to CR1, CR2, CR3 which are tested later on 08-01-2017.

4. Experimental results with graphs

Visual inspection and maximum axial load carrying capacity of the columns before and after corrosion effect and comparison of Reference (undamaged) and corroded (damaged) and corrode repaired with CFRP three categories which are with notation to use further are as follows:

- Reference (Undamaged) R
- Corroded (Damaged) C
- Corroded Repaired (Damaged Repaired) CR

Table 4.1: Comparison Between Corroded and Reference (Non-Corroded)

Sr. No.	R (KN)	C (KN)	Difference (KN)	% Reduced
1	2735	2125	610	22%
2	2674	2198	476	18%
3	2598	2185	413	16%
Avg.	2669	2169.3	499.7	19%

Difference in axial capacity after corrosion is evident of loss of strength maximum to 610 KN (22% reduced) and on an average of 499.7 KN (19 % reduced) which shows how dangerous it is. Also compared in bar graph below:

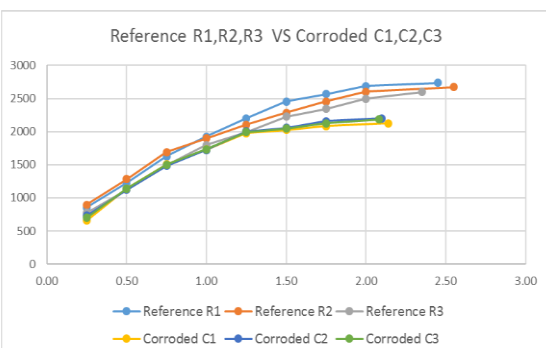
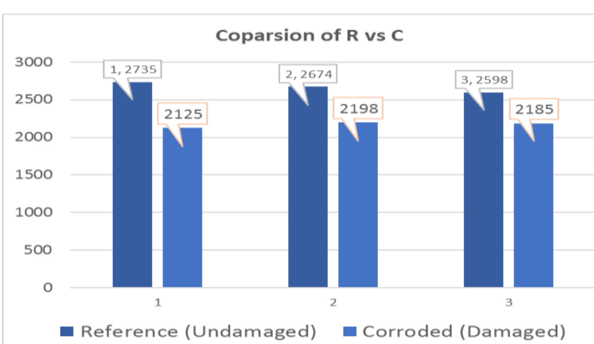


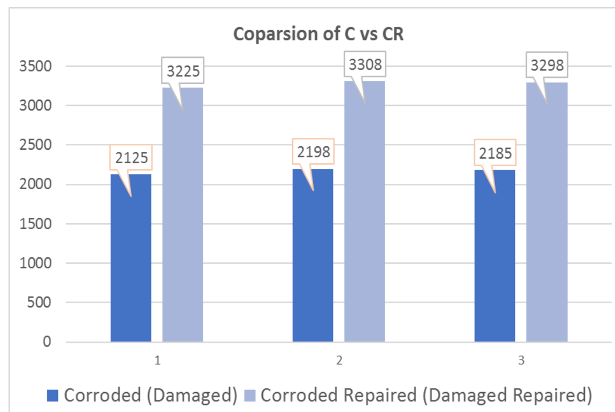
Fig 4.2: Comparison of R1, R2, R3 vs C1, C2, C3



Following tables shows the comparison between Corroded and corroded repaired column.

Table 4.2 : Comparison of Axial Loads B/W C & CR

Sr. No.	C	CR	Difference (KN)	% increased
1	2125	3225	1100	52%
2	2198	3308	1110	51%
3	2185	3298	1113	51%
Average	2169	3277	1107	51%



Difference in axial capacity after repaired by CFRP it is evident of increase in strength maximum to 1113 KN (51% increased) and on an average of 1107 KN (51 % reduced) which shows that damaged sample regain its strength as well as there is also about 23% strengthening as well. Also, compared in bar graph below:

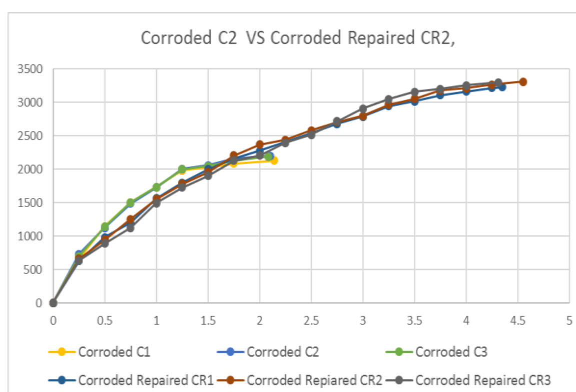


Fig 4.2: Comparison of C1, C2, C3 vs CR1, CR2, CR3

4.1 Comparison between reference (R), corroded (C) and corroded repaired (CR) columns

Table 4.3 Comparison of Axial load in detail B/W R, C & CR

Sr. No.	R (KN)	C (KN)	CR (KN)	Difference B/W R-C (KN)	%age Difference B/W R-C	Difference B/W CR-R (KN)	%age Difference B/W CR-R	Difference B/W CR-C (KN)	%age Difference B/W CR-C
1	2735	2125	3225	610	-18%	490	18%	1100	52%
2	2674	2198	3308	476	-24%	634	24%	1110	51%
3	2598	2185	3298	413	-27%	700	27%	1113	51%
Average	2669.0	2169.3	3277.0	499.7	-23%	608.0	23%	1107.7	51%

As we discuss column no. 01 its shows that after corrosion there was 18% reduction in strength and after repaired by CFRP it gains its strength as well as there are 18% additional increase strength form the original (Reference strength) and it also shows their overall gain in strength increase 52% form the lowest strength (corroded)

As we discuss column no. 02 its shows that after corrosion there was 24% reduction in strength and after repaired by CFRP it gains its strength as well as there are 24% additional increase strength form the original (Reference strength) and it also shows their overall gain in strength increase 51% form the lowest strength (corroded)

As we discuss column no. 03 its shows that after corrosion there was 27% reduction in strength and after repaired by CFRP it gains its strength as well as there are 2% additional increase strength form the original (Reference strength) and it also shows their overall gain in strength increase 51% form the lowest strength (corroded)

On the average to discuss it clear that concrete after corrosion losses its strength up to an average 23% and after repaired by CFRP it overall strength increase to 51%. In which 23% gain and 23% additional strengthening.

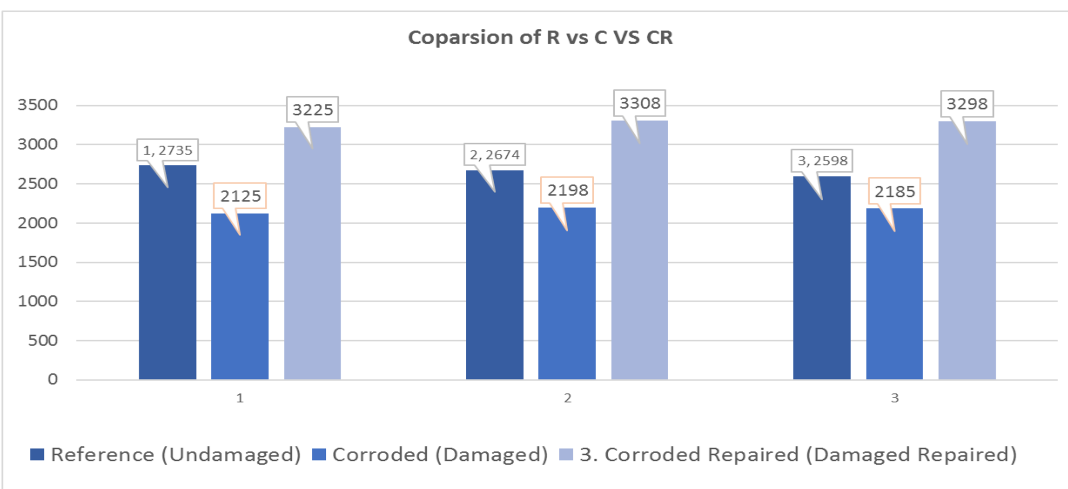


Fig 4.3: Comparison of R vs C vs CR

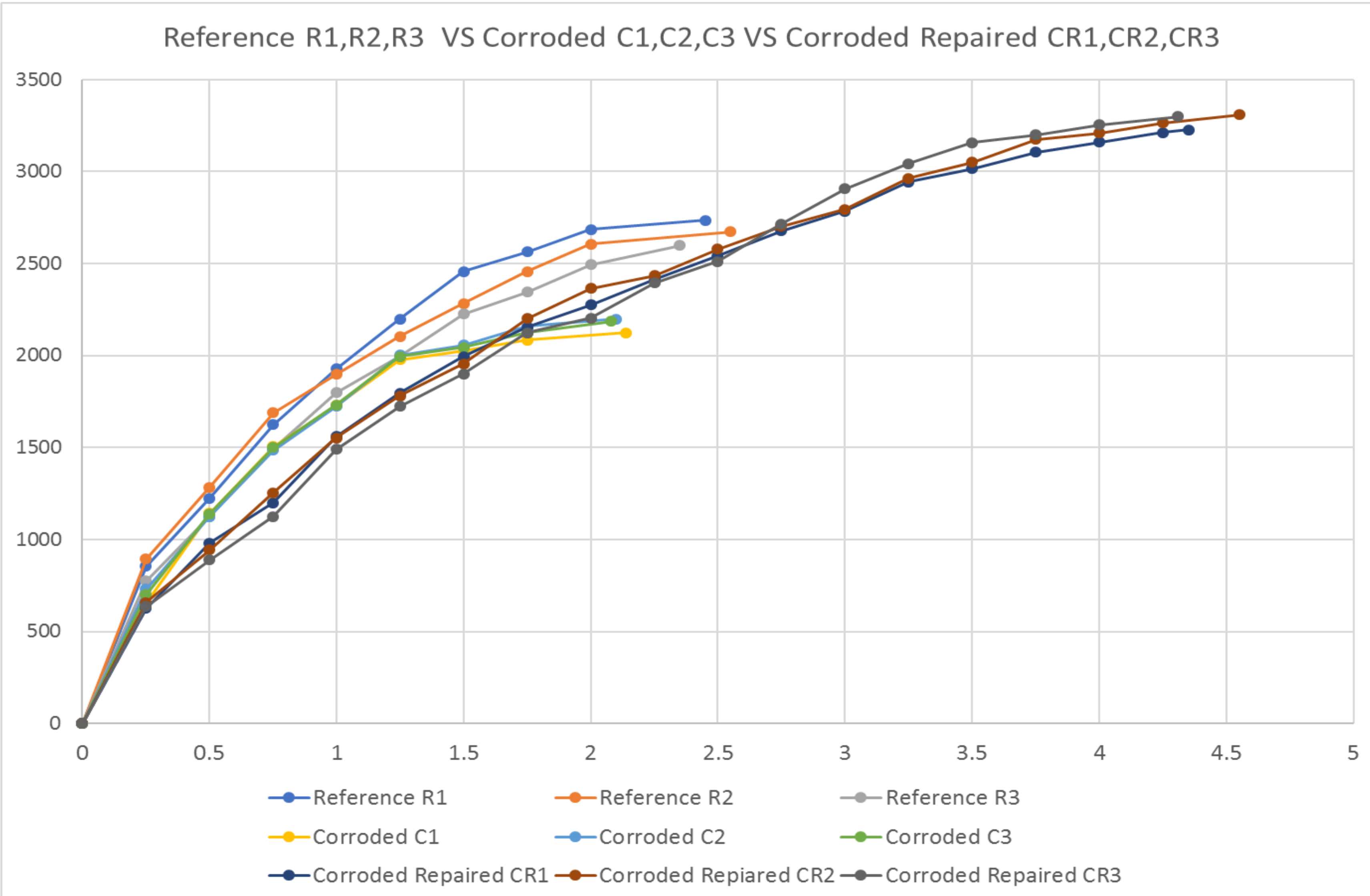


Fig 4.4: Comparison of R1,R2,R3 vs C1,C2,C3 vs CR1,CR2,CR3

5. Conclusion

The conclusions of the research are as under
On the average to discuss it clear that concrete after corrosion losses its strength up to an average 23% and after repaired by CFRP it overall strength increase to 51%. In which 23% gain and 23% additional strengthening.

6. Recommendation

It is recommended that wrapping of corrosion damaged Column with CFRP is useful techniques to repair/strengthen the damaged columns
It is recommended that jacketing with different material such as fiber-reinforced plastic (FRP) products or composite wraps in lieu of conventional steel (Bars) jackets is more useful method of strengthening bridge piers and columns against seismic resistance and it is useful.
For Future research, it is recommended to enhance the humid environment in during half-cell oxidation reaction or response anodic reaction to achieve the more accurate and enhance results. Also work on conductivity of concrete
It also recommended that research may also carried out with other deterioration methods like sulphate attack and alkali-silica reaction.

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