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# Modern Techniques for the Restoration and Rehabilitation of Concrete Structures

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***Abstract:** Civil engineering not only deals with the construction of various structures but also works for their maintenance and rehabilitation. The current era requires efficient and sustainable methods for any job and given that concrete is a material that is heavily relied upon at the present time in construction, therefore its sustainability through the rehabilitation and restoration of buildings is a must and very important. There are many techniques that can be followed in the rehabilitation and restoration of damaged concrete sections, i.e. exposed to cracks, corrosion or disintegration, as each process has its advantages and limitations, which requires the engineer to know the type of damage, the main cause of it and the best way to repair it. Therefore, this paper uses the descriptive methodology to review the latest rehabilitation and restoration techniques used in the treatment of concrete structure including, repointing, grouting, reinforced injection, polymeric materials permitted by fibers and reinforcement of concrete structures, overlays, jacketing, base isolation and stitching. The researcher concluded that these techniques are effective, but each has its determinants of use that must be taken into account before applying them.*

***Keywords:** Rehabilitation, Restoration, Repointing, Grouting, Reinforced injection, Base isolation, Polymeric materials.*

## I. INTRODUCTION

The evaluation of existing reinforced concrete structures has become a necessary and important process for engineers on a large scale due to the aging of existing structures and buildings, as reinforced concrete has become a global construction material during the past decades to this day (Korany, 2011). There are a large number of existing facilities that need either rehabilitation or removal as a result of natural or man-made factors and causes such as, natural disasters, earthquakes, wars, conflicts, and other sudden causes that lead to various degrees of damage. The long neglecting of these facilities and the lack of periodic maintenance, misuse, poor design, etc., leads to deterioration in the condition of these facilities over time (Gangane, Khandve & Dhawade, 2015).

The removal of all installations that do not meet the requirements of the present day in terms of levels of loading or those that show signs of damage is impossible in practice and economically, and therefore it is necessary to conduct a technical, structural and economic evaluation of these establishments, to choose the decision and the best course of action in terms of restoration, support, rehabilitation or removal, in order to continue to invest these facilities safely and economically (Matar, 2018).

The process of rehabilitation of old buildings in construction or restoration of heritage buildings is a special case of repair, and to a large extent there is a relationship between defects and construction systems, as each problem of moisture, settlement, erosion and others has its unique cause and leads to various defects in the structure. Since the causes are unique, the mitigation, restoration, and repair solution also differs because it needs a full and detailed study in reference to the reasons and measures needed to be implemented. Therefore, the restoration engineer must have knowledge of the defects associated with construction systems, in order to facilitate the process of diagnosis, cause and treatment (Narwaria &Tiwari, 2016).

Also, all factors such as the age of the structure, the local climate, construction techniques and ground conditions must be considered in order to develop a specific and individual repair technique and program, since after correct and detailed evaluation of the buildings, it is necessary to make the right decision and the appropriate type of repair, commensurate with the defect and the purpose of the repair; whether if it is a reform to enhance the value or capacity of the structure or a reform that improves the aesthetics of the building, whether it requires adding structural supporting elements or permanent industrial and natural materials (Engindeniz, Kahn & Abdul-Hamid, 2005).

Therefore, there must be a comprehensive rehabilitation and restoration approach starting from evaluation, linking the result with the reason, choosing the appropriate method of restoration, that includes all factors and purposes and ending up by implementing this techniques. Accordingly, what this review paper aims to is to demonstrate the most important and most modern techniques to restore and rehabilitate cement facilities, explaining the importance of each technology and its purpose to be used in the most appropriate and effective way.

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## II. PR PROBLEM STATEMEN

Sustainable development has become a challenge for humanity, especially with the rapid growth of urban expansion, as sustainable development has extended to include engineering works, so there is an urgent need to understand and implement maintenance work for concrete buildings to ensure the sustainability of these buildings, and the sustainability of precious resources threatened with extinction, such as cement and energy (Bhattacharjee, 2016). There is a developing international and national worry about the untimely decay of our installation and structures, especially concrete structures. Concrete cement is one of the most broadly utilized building materials and has end up being practically vital to the present day human progress. Despite the fact that concrete is mechanically very solid, it is exceptionally defenseless to decay and corrosion and accordingly gets harmed and even fall eventually, except if a few measures are received to counter this weakening and deterioration. Such measures would upgrade the toughness of structures and increase its durability. The support of building by maintenance, rehabilitation and restoration is a deep rooted constant procedure. It has been seen that the base (minimum) maintenance of concrete structures require an indispensable methodology which need the presentation of however much preventive measures as could be expected as per the essential built up idea – "Counteraction is in every case superior to cure" (Bhattacharjee, 2015). Maintenance, retrofitting, rehabilitation and restoration represent the quickest developing sector of the concrete industry recently. Over the globe, billions of dollars are spent every year in restoration and rehabilitation of concrete structures. In this manner, the selection and evaluation of materials, defensive coatings and maintenance techniques is accepting increasingly more consideration among Civil Engineers in the ongoing past. The new modern advances and new fix materials, which have been widely being utilized by the developed nations, are likewise being attempted in evolving and developing countries for the purpose of achieving sustainability. This paper demonstrates the modern situation of restoration and rehabilitation process around the world and characterizes the use of those new modern materials and techniques for rehabilitate/restore the building or structure for long term sustainable development utilizing a descriptive review methodology, in which the researcher reviewed the most prominent modern methods and techniques for restoration and rehabilitation based on a set of published articles, online-research, paper and most related studies (Bhattacharjee, 2016; Dandona, 2006).

## III. THE MAJOR CAUSES OF DETERIORATION OF CONCRETE STRUCTURE

Concrete typically gives sound corrosion and deterioration protection as well as strong embedded protection for steel. Over time, reinforced concrete is subjected to wear and deterioration as a result of many factors and causes, which must be recognized and known in order to determine the best method of restoration. One of the most important factors that control concrete deterioration is the design of the concrete structures which governs its performance, where the well-designed and detailed concrete structure will show less deterioration compared to poorly designed ones. The beam column joints are especially probe for defective concrete, if the reinforcement is not properly laid out and the reinforcement is placed (Bhattacharjee, 2016).

Environmental effects represent another cause of deterioration to concrete, as the small cracks in the concrete are the source of access to moisture and carbon-oxide in the atmosphere to the concrete, which attacks the reinforcement and interacts with various components of the concrete. Accordingly, the concrete structures will deteriorate faster and its age or strength will decline faster in aggressive environment (Hollaway et al., 2009) .Moreover, the quality of the materials used in construction must be guaranteed, by various tests, as defined in different construction codes. The attack of total alkali and sulfate leads to early degradation. The cracked materials in the aggregates may weaken the cumulative bonding of the slurry, and reduce the strength. This also can be assured through the qualified supervision over the construction work to be carried out according to specifications. For instance the adherence to the ratio of the proportion of water affects the strength, permeability and durability of concrete (Ma et al., 2017). Corrosion of implanted steel represents the most dangerous reason and advance level for harms to the reinforced concrete structures. It is usually connected to spalling of concrete cover, cracking that is parallel to the reinforcement, spalling at edges, dislocation and swelling. It resembles a cancer, which advances with moderate deterioration procedure and whenever ignored or not taken into consideration in time, it may spread over a huge region and cause broad breaking down and disintegration of basic structural components. It might even prompt to a catastrophic failure, without convenient therapeutic measures. Different causes which make helpful conditions to quicken/spread pace of corrosion including; inadequate cover to reinforcement, use of inadequate concrete ingredients (coarse and fine aggregate) as well as inappropriate water to cement ratio which lead to hairy cracks in concrete (Bhattacharjee, 2016). Apart from these, many other reasons can cause deterioration to concrete structure, such as foundation settlement, lateral movements, poor or lack of maintenance throughout the service life and accidental overload which may lead to different types of cracks that either resulted in a structural distress, reduction of safety or unacceptable aesthetic appearance. In conclusion, the various inappropriate design, environment or implementation conditions as well as aging may lead to a different set of damage, such as degradation, corrosion, disintegration and cracking. So, it becomes necessary to intervene and find appropriate solutions (rehabilitation and restoration) based on the type of damage, its root cause and the right materials and proper maintenance techniques (Alexander et al., 2012).

## IV. MODERN REHABILITATION AND RESTORATION TECHNIQUES

Several modern techniques could be utilized to restore and rehabilitate disintegrated concrete structures.

Some techniques, including, replacing and repointing tends to recover the first state condition of the buildings.
The other techniques, including, grouting, overlays and reinforced injection tends to increase the structural capacity. However, techniques such as external reinforcing, tying, anchoring and center coring are utilized to upgrade protection from lateral and sideways loads. Other more recent techniques were developed, such as base disconnection (foundation isolation) which is utilized to diminish the seismic powers acting on the base of structures (Modi & Patel, 2015). Accordingly, some of those modern techniques were reviewed in this section:

### A. Repointing

Mortar joints could disintegrate or spall after some time because of drainage of water, freeze-defrost cycles, or not filling the concrete joints entirely. Additionally, de-bonding and partition splits along the joints may be caused due to differential movements. Thus, the process by which the disintegrated mortar is removed from the joints and supplanting it with new mortar, is called repointing. It is prescribed that joints be racked or ground sponsored to a profundity of multiple times the joint stature with at least 13 mm from the proposed mortar surface. The new mortar is put in layers and tooled when it is become hardly thumb printed. The new mortar should be similar as much as possible with the current disintegrated mortar in properties, texture and color (Korany, 2011).
Repointing is required if: mortar is profoundly disintegrated (in excess of 13 mm) or has dropped out, hairline splits or bigger have shaped in the mortar, the concrete structure and mortar do not stick to, bringing about a break or a hole between the two, or the mortar is setting freely in the joint (Korany, 2011).

### B. Grouting

Grouting is a procedure that includes filling the breaks and cracks to reestablish the first quality of the concrete structure. Grout can be infused into concrete elements such as beam, column, etc. to anchor its components or to fortify and solidify its elements firmly filling empty units or open depressions. This method has functioned admirably for historic concrete structures and can be increasingly viable if the aimed structure to be fixed is pre-wetted. It is critical to guarantee total filling and prevent back shrinkage as water is absorbed from the grout in the case of utilizing a polymer, non-shrinkage grout, or epoxy altered grout (Jumaat et al., 2006).
Several concrete walls were built from two external leaves of un-coursed stone or un-coursed stone blended in with block and a rubble inward infill of littler bits of stone regularly including voids. Hence, injecting cementitous grout is an effective technique to restore these walls by collecting and binding their loose parts together into a strong structure. Grout is infused through cylinders in gaps penetrated between the stone units to a profundity of at any rate half of the wall thickness at 0.5 m to 1.0 m interims. A quick setting mortar is utilized to fix the cylinders and seal surface splits between stones, if the surface is not plastered (Gowri, 2016).

Research has indicated that appropriately planned cementitious grouts can be infused into concrete walls to fill breaks going from 0.08 mm thickness to 12 mm and bigger. Utilized in blend with retrofit grapples, grouting can guarantee composite activity of multi-wythe walls, and reestablish the integrity of the damaged concrete walls. The plan of grout infusion tactics must consider the expansion in wall mass and the non-structural results, for example, the potential chemical reaction between the grout and encompassing materials and changing moisture paths inside the wall . An injection of of low thickness epoxy was seen as powerful in fixing splits as little as 0.13 mm. however, epoxy infusion requires high expertise to prevent the issues that may emerge from inappropriate application, for example, lacking infiltration, inappropriate relieving, nearness of cavities, and affectability of epoxy to temperature (Korany, 2011).

### C. Reinforced injection

This kind of injection utilizes methods and hardware like the grouting system that was mentioned previously. The gaps bored in concrete structure are, in any case, deeper and more frequent, slanted through the wall thickness. The specific number and position of the gaps rely upon the structural state of the concrete building. Steel bars are embedded in each gap before the infusion of grout. Strengthened infusion is typically performed under high tension (Mason, 2008).
Grout must achieve satisfactory bond strength among steel and contiguous concrete structure to move applied burdens. This method allows the formation of strengthening networks both locally to guarantee viable associations between crossing walls as appeared in Figure 1, and all inclusive on the whole wall to either join breaks or increment strength. This system permits the concrete wall or its portions to go about as a support component, where the swaggers are slanted portions of unreinforced building. It is an adaptable and brisk overhauling method practically identical to grouting. In any case, it is not a reversible mediation and if not satisfactorily analyzed; its consideration can result in non-consistency in quality and firmness (Elmoneam Zaky, 2013) .
Korany (2011) mentioned in his research an evaluation of the adequacy of various fix and retrofit plans utilizing grouting and reinforced injection to recognize appropriate grouting materials and methodology for retrofit of concrete structures. Eleven tests were directed on four shear walls in their unique condition and after they were harmed and fixed with various techniques. Three walls were strong ones having indistinguishable geometries and a height to width proportion of 0.6 while the fourth had an opening in the middle to represent an open front wall. The test outcomes demonstrated that the infusion (injection) of cementitious grout joined by the fix and supplanting of limited harmed regions with comparable materials can reestablish the first quality and solidness of unreinforced brick work walls. Without huge voids or splits grout injection without anything else was not helpful in upgrading the strength.

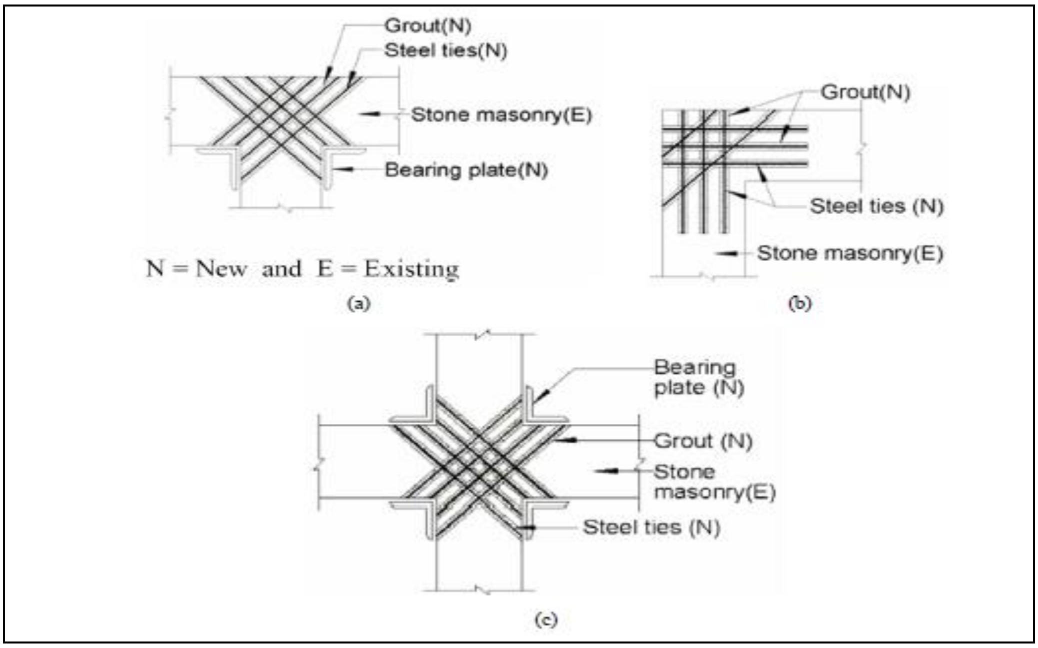


**Fig 1: Reinforced injection at intersecting masonry walls, (a) T-intersection (b) L-intersection (c) X-intersection (Korany, 2011)**

### D. Polymeric materials permitted by fibers and reinforcement of concrete structures

The newly developed composite materials are being used extensively and unprecedented in strengthening concrete structures where panels made of polymeric materials permitted by glass or carbon fibers are used to support and rehabilitate the amount of tiles and concrete roof tiles to increase their resistance to deficiency and bending. Chips made of polymeric materials permitted by glass or carbon fibers are also used to reinforce and rehabilitate the concrete beams to increase their resistance to shear or twisting torque. These chips are also used to reinforce concrete columns and increase their resistance to vertical loads or to rehabilitate them to increase the protection of earthquakes. Chips and panels have also begun to be used to reinforce concrete brick walls and old building walls in separate parts of the world (Hollaway, et al., 2006).

### E. Tying and anchoring

Tying and anchoring hardens the individual structural components, and empower composite conduct of the structure rather than autonomous response of the single components. Tying and anchoring components additionally has the benefit of damping the segment's reaction. Specifically, increasing the stiffness as well as damping the reaction of diaphragms can altogether decrease the out-of-plane relocation and displacement on outside of walls (Hohmann, 2013) .

Absence of appropriate tying down and tying of floors and rooftop to walls limits the steadiness of concrete structures under sidelong loads. Inappropriately tied down concrete walls were seen as powerless against seismic burdens. But where grouting-in of grapples to restore the original construction, bored in retrofit jolts, extension anchors, or epoxy sock grapples are utilized for mechanical association. Steel edges, or other joining components, are typically required to transfer force from the first structural element to another one adequately as appeared in Figure 2. Enormous shear jolts can be utilized to attach concrete walls to rooftop and floor diaphragms. Establishment comprises of penetrating moderately enormous gaps (65 mm in measurement) and drypack a steel jolt to a profundity of 200 mm into the concrete wall. Portland concrete drypack materials or industrially accessible non-contract grouts are utilized for grouting. The most basic part of the structure is to satisfactorily grapple the jolts to structure to guarantee satisfactory stiffness (Korany, 2011).

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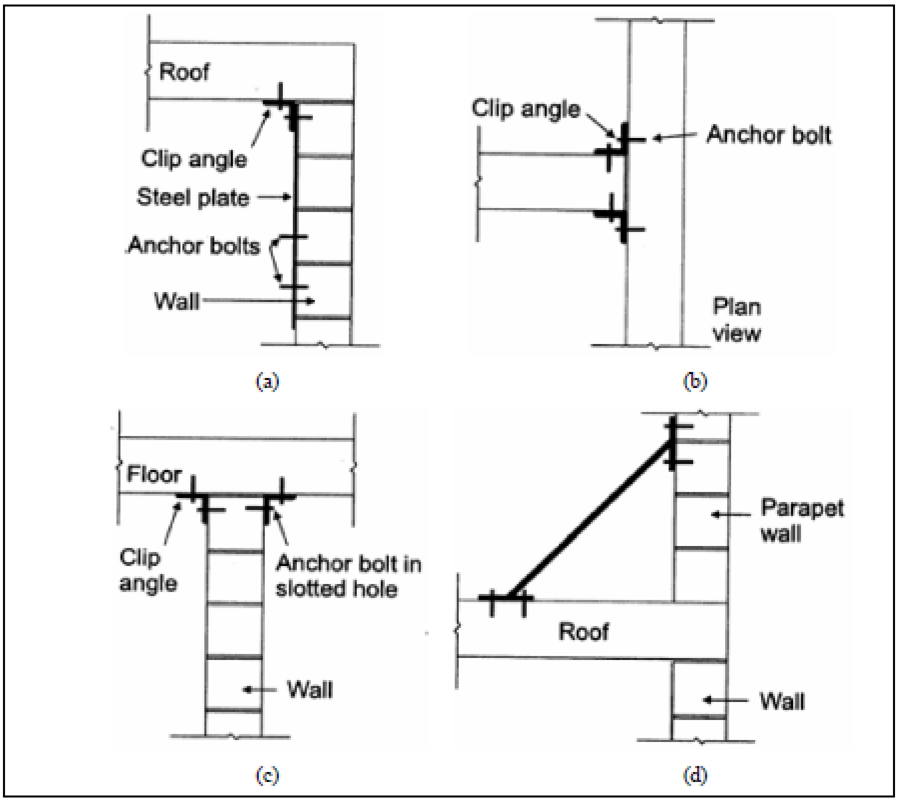


**Figure 2: Tying and anchoring masonry walls, (a) hold down of roof (b) intersecting walls (c) floor to wall (d) bracing parapet (Korany, 2011)**

### F. Overlays

When covering concrete structure elements with a surface layer is worthy, the utilization of an outer strengthening overlay can be a viable restoration technique. The upgraded strength and flexibility of this restoration system has merit for out-of-plane bending of concrete structures because of seismic stacking. Be that as it may, the procedure is non-reversible and hard to fix later on. The life expectancy of the structure gets constrained to that of the overlay (Gowri, 2016).

This kind of overlays techniques are accomplished by utilizing shotcrete, fortified mortar (ferrocement), or cast set up strengthened cement. The base thickness of a strengthened solid overlay is in the request for 100 mm. The thickness of shotcrete and mortar ranges from 30–50 mm. The new overlay structure element is self-bearing, regardless of whether they are fundamentally associated with other existing structural element. Sufficient total size and added substances are utilized to improve adherence and resist creep. A steel fortifying cross section (mesh) made with bars 3 to 4 mm in width is commonly utilized. Shotcrete overlays have been found to decrease the outrageous tensile loads in structure by around 33% and by near half in the most fundamentally stressed areas of the structural element. Surface mounted steel plates and edges have been utilized to reinforce the concrete walls (Korany, 2011).

### G. Jacketing

The deteriorated columns, piles or piers can be strengthened by encasing the concrete structure by a new concrete jacket, where the diameters and the number of reinforcing steel bars in this new jacket are dependent on the requirements that led to the necessity of making this jacket. This rehabilitation technique is done through the following steps (Elmoneam Zaky, 2013):

1) The white layers are removed and the concrete surface is cleaned well.
2) All surfaces are lubricated in a manner that does not affect the integrity of the shaft.
3) Wrought iron is planted to connect the new jacket nodes in both directions at distances of 25-50 cm. Wrought iron's is cultivated by making holes in the surface of the column with a diameter of 2 mm more than the diameter of the edges in any limits 5 to 7 times the signal diameter.
4) Clean the holes thoroughly with compressed air and paint the inside with an epoxy then fill it with epoxy mortar 165 and plant the signal and take into account that the signal is long enough to connect them with the new fabrics of the shirt with a wire strap.
5) Wrought iron is planted for the vertical iron with the same number and diameter used in the vertical rebar with a length of not less than 50 times the signal diameter.
6) These wrought irons are grown by making holes in the reinforced concrete bases or in the beams according to the case. The diameter of the holes is 2-4 mm larger than the signal diameter and the depth is within 5 to 7 times the signal diameter.
7) Clean the holes with compressed air, apply epoxy, and then fill it with a chemical powder, which is then used.

8) The vertical iron, then the stirrups, shall be installed according to the design of the column jacket.
9) The surface of the shaft is to be painted with epoxy to bond the new concrete to the old concrete. It is necessary to pour the concrete of the jacket before drying the paint.
10) The jacket shall be poured from concrete. The jacket shall be made of non-shrinking concrete consisting of fine aggregate, sand and cement with a percentage of not less than 400 kg / m3 and anti-shrinking additives such as ADVET or BVS or ADF as a minimum of 6 kg / m 3.
11) The concrete of the jacket shall be cast either by the Shotcrete or by regular formwork, by making holes in the tension, on the roof tile, and pouring the jacket in stages.

### H. Base isolation

Base detachment is a substantial technique for the decrease of seismic danger of concrete structure. Enormous cyclic deformations dissipate the vibration load and frequency transmitted starting from the ground at the cost of halfway or absolute damage. Base isolation gives the energy and vibration frequency dissemination instrument at the base and fundamentally diminishes the flexibility request on the superstructure. Be that as it may, the troubles of construction and the intricacy of building a disengaged structure make base separation a technically challenging solution that ought not to be attempted casually (Patil & Reddy, 2012).
Base isolation frameworks utilize extraordinary direction with sandwiched layers of steel and elastic to uncouple the structure from the even parts of the ground movement because of a seismic tremor, while supporting gravitational burdens. The extraordinary direction stretch the structure's normal time of vibration adequately and lessen the degree of transmitted energy. The bearings likewise disperse a portion of this frequency and control the relative removal between the structure and the ground. There are three kinds of base isolators: sliding, elastomeric and a composition from those two kinds (hybrid). The elastomeric type, appeared in Figure 3, consists of profound elastomeric cushions sandwiched between two steel plates. The cross hybrid framework is a blend of the elastomeric and sliding isolators (Korany, 2011).

### I. Stitching

It is a rehabilitation technique utilized in cracks to preserve total interlock between aggregate and provide additional reinforcement to reduce the relative movement of concrete slabs at cracks. It is also utilized in longitudinal joints to prevent plaques from separating (Elmoneam Zaky, 2013).
This technique is carried by utilizing steel or iron dogs with different length, so that the bars are bent in a wide flat U shape between 1-3 feet long and with ends of about 6 inches in length. The stitches are on the side that opens first, and if necessary, the areas adjacent to the construction are strengthened to take the additional stress. Sewing dogs must be of variable length and / or direction, thus, the tension transmitted through the crack is not transmitted on one plane of the section, but is spread over an area.In order to resist shear along the crack, an oblique stitches maybe used as appear in figure 4 (Elmoneam Zaky, 2013).

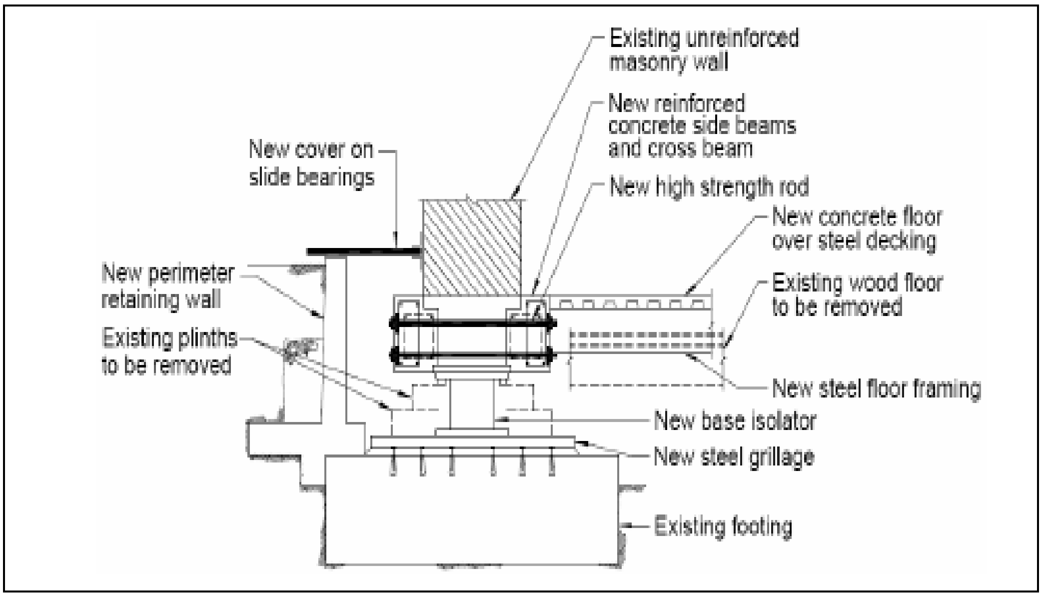


**Figure 3: Base elastomeric isolator for exterior wall (Korany, 2011)**

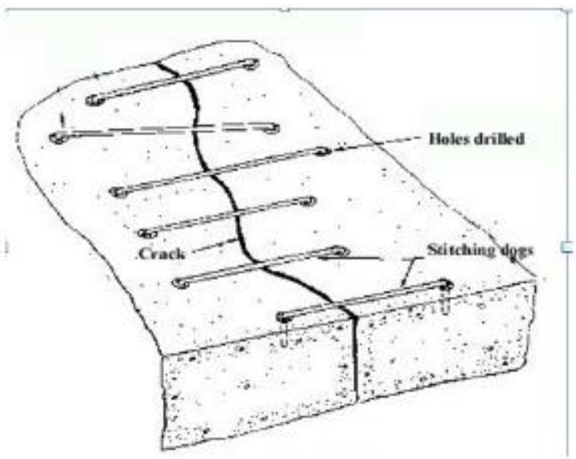


**Figure 4: Stitching deteriorated concrete (Elmoneam Zaky, 2013)**

## V. RESULTS

The following table 1 show the results of the modern **Modern Techniques for the Restoration and Rehabilitation of Concrete Structures** and their sources studies

**Table 1: summery for the sources of studied techniques**

| The Modern Techniques | The sources study |
|---|---|
| Repointing | Korany, 2011. |
| Grouting | Juatt et al., 2006. Gowri, 2016. Korany, 2011. |
| Polymeric materials permitted by fibres and reinforcement of concrete structure | Hollaway, et al., 2006 |
| Reinforced injection | Mason, 2008. Elmoneam and Zakey, 2013. Korany, 2011. |
| Tying and anchoring | Hohmann, 2013. Korany, 2011. |
| Overlays | Gowri, 2016. Korany, 2011. Elmoneam and Zakey, 2013 |
| Base isolation | Patil and Reddy, 2012. Korany, 2011. |
| Stitching | Elmoneam and Zakey, 2013 |

## VI. CONCLUSIONS

Reinforced concrete structures are often subject to disintegration, cracking, and erosion due to several causes and natural and human factors, which is an urgent necessity to assess the condition of these facilities and their levels of damage, in order to ensure safe and sound investment and take the necessary measures for that.

Restoration and rehabilitation are one of the most prominent of these measures that are necessary to take to repair the affected areas or to reinforce the entire structure. They extend the life of the building and help to restore it instead of demolishing it or rebuilding it which costs a lot and violates the principles of sustainable development that are essential to the progress of societies today.

Before starting repair, it is important to determine the root cause of the deterioration. Incorrect diagnosis may lead to improper selection of materials and repair techniques, leading to the failure of the repaired area again. If the cause is correctly identified, successful repair can improve the strength and durability of the structure, and thus extend its life.

Once the cause has been identified, the repair technique must be chosen, and the method that should be adopted to repair or restore the structure depends on the cause, extent and nature of the damage, the function and importance of the structure, the availability of appropriate materials, and a thorough knowledge of the behavior of the materials used for long-term repair work. A variety of new materials and modern effective solutions have been developed, but in this research paper a group of them has been reviewed and we have found that:

- When performing properly, the repointing technique restores the aesthetic appearance of the building and improves structural performance and weather resistance.
- Injection and grouting can restore the integrity of damaged concrete structure; however, the effectiveness of injection and grouting techniques largely depends on the compatibility of the physical, chemical, and mechanical properties of the original construction with the injected materials.
- Although tying and anchoring by attaching additional structural members is an effective technique, it may adversely affect the appearance and space use.
- Base isolation is a modern technology used to reduce seismic exposure to squat buildings. However, this technique is difficult to implement and expensive.
- The newly developed composite materials are widely used and unprecedented in strengthening concrete structures where panels made of permissible polymeric materials from glass or carbon fiber are used to support and rehabilitate the amount of tiles and concrete roof tiles to increase their resistance to deficiency and bending, which is one of the most effective techniques now.

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