Study on Pre-fabricated Modular and Steel Structures

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Abstract

Recent devastating earthquakes of 7.8 magnitudes in Nepal on 24-04-2015 had destroyed many houses and took many lives. These many losses are due to poor building techniques and heavy building materials. In the developed countries like Japan, China, etc. the earthquakes do not affect the lives and destroy the houses. This is because they use the pre-fabrication building techniques and steel or aluminum frame structures rather than heavy concrete building structures.

The prefabricated house is constructed by light steel frame to sandwich panels for the building envelope materials, as a standard module for space series combination of components, the bolt connection, and the new concept of environmental protection economic activities in prefabricated house. The prefabricated components are brought to the site and erected using building block type construction. Work is never delayed by curing time or missing materials and can be completed for 30 to 45 working days. Further study shows that it can also lower the total cost of the project by 12 percent as compare to the traditionally build house using traditional materials such as CHB (Concrete Hollow Blocks).

This paper includes the study on steel structures and pre-fabricated structures. In a general survey, many people were asked about the types of houses they prefer; one common reply was earthquake resistant and economical houses. This paper also includes analysis and research on the quality, strength, environment friendly, costing and the comparison between the traditional buildings and pre-fabricated buildings. The study aims to introduce and to provide more knowledge about modular house to educate the market and to address the concern of every sector of the society especially the depressed areas of the society for a beautiful, stable and affordable shelter.

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Keywords: *pre-fabrication, aluminum frame structures, earthquake resistant structures, economical houses, environment friendly, CHB, affordable shelter*

I. INTRODUCTION

The terminology of "Prefab" is used as a short for "prefabricated buildings"; Prefab is a broad term that encompasses several different types of buildings. Technically, any home that has sections of the structure built in a factory and then assembled on site can fall under the "prefab" designation. The prefabricated house is constructed by light steel frame to sandwich panels for the building envelope materials, as a standard module for space series combination of components, the bolt connection, and the new concept of environmental protection economic activities in prefabricated house. In this competitive world, no countries want to be backward and less developed than any other. Nowadays, the developed countries are in the front of development of sciences and technologies such that they are looking for the probability of lives in another planet. The world became so advanced that they even don't have time to look after the housing and constructional works. But there are also some countries in this globe which even are not providing the shelter for their people. People of some countries like Nepal, India, Bangladesh, etc. don't have a roof to hide themselves from heat and cold. Moreover, the recent earthquake of 7.8 magnitudes in Nepal destroyed many houses. The research from many agencies and expertise shows that the most of the destroyed buildings were traditionally built and the materials used were not tested or certified.

As we all know, in building the conventional and traditional buildings, it takes much more time and the costing is also very high. Also, there will be more wastes and environment will be polluted; labours are also not safe while construction traditional buildings. If these many problems are there in following the conventional trend, why should not we look for the easier and best way for constructional work? Yes. We have to follow the new techniques i.e. Pre-fabricated Modular and steel structures. This method of building structures will minimize the constructional cost, time and wastes. But it increases the quality of the building, efficiency of the work, and the beauty of the buildings. Both Modular and Panel Built fall under the umbrella term of prefab. Modular house is the culmination of one type of building system. The building process starts with efficient modern factory assembly line techniques. The prefabricated components are brought to the site and erected using building block type construction. According to McGraw-Hill construction's report, 76% of respondents indicate that prefabrication/modular

construction reduces site waste—with 44% indicating that it reduced site waste by 5% or more. In addition, 62% of respondents believe that these processes reduce the amount of materials used—with 27% indicating prefabrication/modularization reduced materials used by 5% or more.

The objectives and scope of prefabricated buildings are as jotted below:-

1. To reduce the construction time and it's cost.
2. To minimize the wastes and make it environment friendly.
3. To replace the traditional or conventional way of construction with modern tools and technique.
4. To build light weight building and make earthquake resistant and resistant to adverse climate.
5. To minimize the in-site construction.
6. To minimize the use of aggregates, bricks, rebars, cement, aggregates and excessive water.

A. Concept of Modular Structure

Cellular structures, cellular modules and modular buildings

Modular construction as a concept is not a new idea. The motivation behind this movement is in the promise to gain advantages related to standard procedures. Different approaches of modularity can be identified. Main possible approaches are: i) manufacturing of identical modules (no customization), ii) mass-customization of modules according to the needs of project in question, iii) manufacturing of free-form unique modules. Architectural possibilities are naturally increasing when going towards higher variability of modules. However, all approaches share the production philosophy where industrialized and standardized production is targeted.

A cellular structure is defined as a structural component targeting the minimization of the amount of used material to reach minimal weight and minimal material cost. A honeycomb shaped structure is an example of such cellular structure. Modular construction represents a new kind of skeletal structure (compare Hong et al. 2011). The basic idea is that the modules can bear the load of the other modules, and thus separate supporting structures are not required. Modular construction is also a special case of modular construction where even multi-storey buildings can be made from volumetric modules, the size of which can comprise a whole dwelling unit.

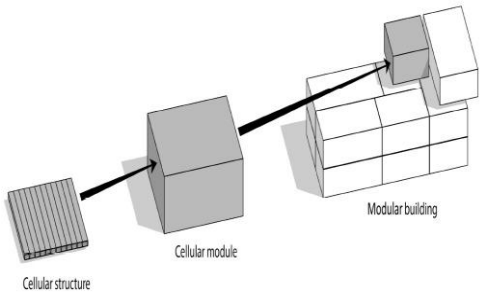

Fig: Concepts Modular Structure

B. Classification

The Prefabrication is classified as follow from the view of degree of Pre-cast construction.

- Large-panel systems
- Frame systems
- Slab-column systems with walls
- Mixed systems

C. Necessity to Adopt Prefabrication Method

The science and technologies in developed countries are moving very fast. They have no time to look behind. In such time, there are still some countries which follow conventional way of building and waste their crucial time and money. Also, by the strong earthquake in Nepal many buildings and structures were destroyed and the country is pushed many years back. Therefore, to develop the nation in minimum time, minimum cost without disturbing the environment, Prefabrication Methods are very much necessary.

D. Characteristics are to be Considered

- Easy availability.
- Light weight for easy handling and transport, and to economies on sections and sizes of foundation.
- Thermal insulation property.
- Easy workability.
- Durability in all weather conditions.
- Non-combustibility.
- Economy in cost, and
- Sound insulation.

E. Advantages

The main advantages of prefabricated structures are assembly of finished elements on site, self load bearing and quick execution, which have favoured their use above all in industry.

- Self-supporting ready-made components are used, so the need for formwork, shuttering and scaffolding is greatly reduced.
- Prefabricated components speed up construction time, resulting in lower labor costs.
- There are less wasted materials than in site-built construction.
- Construction time is reduced and buildings are completed sooner, allowing an earlier return of the capital invested.
- The mechanization used in prefabricated construction ensures precise conformity to building code standards and greater quality assurance.
- On-site construction and congestion of site is minimized.
- Better quality control can be achieved in a factory assembly line setting than at the construction site.
- Quality control and factory sealing and design can ensure high energy efficiency.
- Prefabrication site can be located where skilled labor is more readily available and the costs of labor, power, materials, space and overheads are reduced.
- Time spent due to bad weather or hazardous environments at the construction site is minimized.
- Prefabrication allows for year-round construction, work is not affected by weather delays (related to excessive cold, heat, rain, snow, etc.).
- Less wastage of construction material.
- Advanced materials such as sandwich-structured composite etc. can be easily used, improving thermal and sound insulation and air tightness.
- Independence of climatic condition.
- Worker safety and comfort level are higher than in site-built construction.
- Computerization of the production process permits a high degree of customization, at an affordable cost.

F. Disadvantages

Despite these benefits, node discontinuity is the most critical factor in the event of an earthquake, since the risk of losing the support of the horizontal prefabricated structures under seismic activity is what experience has indicated as being the most frequent. Creating this continuity can also mean losing the advantages of the prefabricated structure. In seismic zones load bearing elements are not allowed where the transmission of horizontal seismic activity is only by friction due to the weight of components.

There are other disadvantages too. They are as follows:-

- Leaks can form at joints in prefabricated components.
- Transportation costs may be higher for voluminous prefabricated sections.
- The requirement to transport manufactured homes or modules to their intended site can mean that prefabrication potential may be limited for infill projects in inner city areas.
- Increased production volume is required to ensure affordability through prefabrication.
- Higher initial construction cost.
- Lack of background research information.
- Time consuming in the initial design development.
- Large prefabricated sections require heavy-duty cranes and precision measurement from handling to place in position.
- Larger groups of buildings from the same type of prefabricated elements tend to look drab and monotonous.
- Local jobs may be lost, if the work done to fabricate the components being located in a place far away from the place of construction.
- Prefab structure means that there is less local working on any construction project at any time.
- Design and construction of modular buildings, require high levels of collaboration among project parties, especially architect, structural engineer and manufacturer.
- Prefabricated buildings typically depreciate more quickly than traditional site-built housing because of its shorter economic life.

II. LITERATURE REVIEW

The study has successfully established the fact that proportion of prefab content has a significant relationship with the cost performance and time performance of the project. The study has quantified the benefits of employing prefab technology in light to medium commercial building projects by concluding that 77% prefab content in light to medium commercial buildings can result in 100% or more cost performance and similarly 74% prefab content can result in 100% or more time performance. Findings of this study are likely to encourage the uptake of prefab technology in construction process. However, factors other than prefab content might be responsible for the cost and time performance such as quality of project management, site characteristics, procurement strategies etc. are recommended for further investigations (Shahzad, W.M, Mbachu, J. and Domingo, N. (2014).

Conventional wisdom would lead one to believe that the production of prefabricated housing

under controlled conditions using mass production technology and employing a generally semi skilled workforce would result in a product less expensive or at least competitively priced to that of conventionally built homes. Indications were appeared to support the contentions made so often by the prefabrication industry that their product is more cost effective than conventional construction (Stefan J. Weidemann, 1990).

Recycled-content and reused materials are being used in modular and prefab products to increase its sustainability; challenges include off-gassing and ensuring materials are nontoxic. (BC Housing Manufactured Housing Association of BC Real Estate Institute of BC, 2014).

According to WHE reports, no major efforts have been reported regarding seismic strengthening of precast concrete buildings. However, seismic strengthening of precast frame buildings was done in Uzbekistan (WHE Report 66). The techniques used include the installation of steel straps at the column locations and reinforcing the joints with steel plates to provide additional lateral confinement of the columns, (Svetlana Brzev).

According to McGraw-Hill construction's report, 76% of respondents indicate that prefabrication/modular construction reduces site waste—with 44% indicating that it reduced site waste by 5% or more. In addition, 62% of respondents believe that these processes reduce the amount of materials used—with 27% indicating prefabrication/modularization reduced materials used by 5% or more.

Abiding by the credo that "the best energy is saved energy", the presented concrete wall system achieved sustainable, healthier environment and living ambient for occupants, (Milovanovic, Stirmer & Milicevic

III. MATERIALS AND METHODOLOGY

A number of new construction materials are starting to be used as components in prefab housing. Here are two of them:

i. Structural Insulated Panels (SIPs)
ii. Insulating Concrete Forms (ICFs).

A. Structural Insulated Panel (SIP)

A structural insulated panel (SIP, also called a sandwich panel) consists of a pair of oriented strand board (OSB) or plywood panels with a core of extruded polystyrene (EPS) foam in between, attached with an adhesive. Panels are available in a variety of thicknesses. They are usually produced in 8-ft-tall panels, but they can be customized as per the requirement.

Its peculiarity is that the foam in the core is the best insulator and its thickness determine the value of insulation. The foam core forms a continuous energy barrier, and the smaller number of studs leaves less opportunity for heat conduction. SIPs are fabricated to very close (1/8 inch) tolerances, and the edge connections, which vary by manufacturer, are designed to fit snugly together. The best thing about SIPs is their resistance to insects. While the EPS foam core provides no nutrition to insects, it offers an easy way for them to tunnel into the structure. Borate additives can be mixed into the foam during manufacture, providing some amount of insect resistance. De-lamination caused by failure of the adhesive is a major concern because it would affect the ability of structural SIPs to carry load.

B. Insulating Concrete Panel (ICFs)

Insulating concrete forms (ICFs) are a prefab construction material which consist of hollow EPS foam blocks that are stacked and glued together on-site, creating a form that is filled with reinforcing bars and concrete. The unique property of ICFs is that the foam blocks are not removed after the concrete hardens; instead, they help insulate the building, while the concrete provides structural integrity. Although ICFs are really a hybrid prefab material, they offer many of the cost and environmental benefits of pure prefab. In comparison with traditional concrete construction, it is faster to stack ICF foam blocks than to build a wood form, and since the foam blocks are not removed, there is much less wastes. It can be also used as sound proof. The concrete must be fluid enough to fill the foam blocks without leaving air voids, which would severely detract from the structural integrity of the finished wall, yet must be solid enough not to exert too much horizontal pressure on the foam, which can cause the forms to fail. Insect can attack this structure so, insect-resistant additives can be mixed into the polystyrene foam.

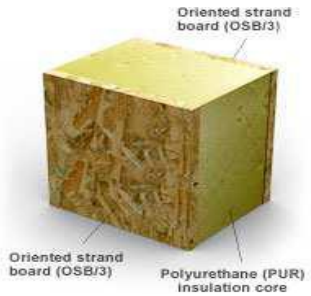

Figure: SIPs

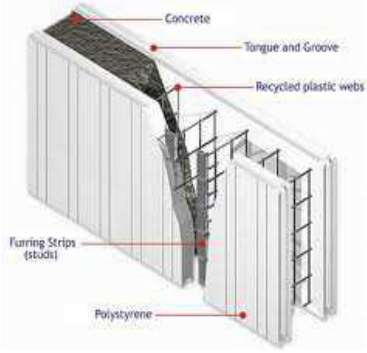

Figure: ICFs

C. *Prefab Materials in Marke*

- Zincalume Steel
- Colorbond Steel
- Aerocon Panels
- FRP Corrugated Sheets
- Color Coated Galvalume Sheets

- EPS Corrugated Panel
- CGI sheets
- UPVC roof
- Asphalt shingles
- PUF Sandwich Panel
- EPS Sandwich Panel
- Solid Cement wall Panel
- Dry Wall System using cement boards
- Different claddings/siding materials

1) *Color Coated Galvalume Sheets*

These sheets are preferred material for roofing and wall cladding. They combine the strength of steel and corrosion protection of zinc or zinc/aluminum alloy coatings. These are available in various colors, have appealing aesthetics, long life, durability and easy installation. Color coated Galvalume sheets of AZ150 class (aluminum zinc coating of 150 grams per sq. meter) with coated alloy of 55% Aluminum, 43.5% Zinc and 1.5% Silicon and of approved color with top surface coated with 20-25 microns of polyester coating and bottom service coat with 5-10 microns over and above epoxy primer, basic steel conforming to IS -513, ASTM A 792 M / AS 1397 – GALVALUME COATING, ASTM A 924 for mechanical properties and ASTM 755 for paint coating. Overall width of 1120 mm and laid width of 1060 mm, with six crests of 25 mm, spaced at 206 mm center to center, and with a stiffening rib (28mm) of 3mm height at the centre of each valley of the sheet, with two anti–capillary grooves with long return leg on either side of each crest.

2) *Zincalume Steel*

This product is high corrosion resistant and thermal efficient hot dipped zinc-aluminium alloy (55% Al - Zn) coated steel with spangled surface conforming to AS 1397 available in Grade 300 & 550. Thickness of coating conforms to AZ 150 / AZ 200 (AZ 150 - 55% Al-Zn alloy coating of 150 g/m2 minimum).

3) *Colorbond Steel*

The Colorbond steel is comprising of Zincalumer steel substrate as base material and coatings of Zn-Al alloy Coating, Conversion Coating , Universal Corrosion Inhibitive Primer (Nominal 5µm) and Finish Coat (Nominal 20µm) on the front side and similarly with Backing Coat (Nominal 5µm) on the back side.

Colorbond steel has good resistance to accidental spillage of solvents such as methylated spirits, white spirit, mineral turpentine, toluene, trichloroethylene, dilute mineral acids and alkalis. However, all spillages should be immediately removed by water washing and drying.

Fig: Colorbond Steel

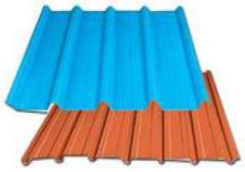

Fig: Color Coated Galvalume Sheets

4) *Sandwich Panel*

These are used for insulation of roofing and walling in the building. It consists of one or both side metal Galvalume sheet and PUF insulation in between. These have high thermal efficiency and significant mechanical strength, which makes it possible to go for larger spans as well as large partition walls.

5) *Aerocon Panels*

Aerocon panels are slim, lightweight wall panels that perfectly substitute plasterboard, plywood, particleboard and brick wall because of their sheer strength. Their low weight, ductility, fire and moisture-resistance properties make them hardy survivors of climatic and accidental disasters. Being pre-fabricated, they are also easy to install and reduce construction time by 80%. Aerocon panels are certified Green product by Indian Green Building Council. The Aerocon panels help to conserve natural resources. Fly ash, which is recycled waste, is utilized in making these panels. No wood is used in the manufacture of this product and little water is required during construction. These panels are also poor conductors of heat, therefore making a building energy efficient. Aerocon panels are available in the following sizes:

Size Thickness
600 x 2400 mm 50 and 75 mm
600 x 2700 mm 50 and 75 mm
600 x 3000 mm 50 and 75 mm

6) *FRP Corrugated Sheets:*

Fibre-reinforced plastic (FRP) (also fibre-reinforced polymer) is a composite material made of

a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, basalt or asbestos. The polymer is usually an epoxy or a polyester thermosetting plastic. FRPs are commonly used as roofing material as it is light weight, strong and resistive to deforming forces. They are usually rust and termite proof. They have good impact resistance; possess fire retardant properties and resistant to external weather conditions. These are normally available in 0.4 mm to 5.0 mm thickness. They are also available in transparent & opaque varieties. These are extensively used in parking sheds, shelters warehouses and residential and industrial roofing etc. where weight saving is an essential criteria.

Fig: FRP Corrugated Sheet Fig: Sandwich Panel

7) ***EPS and PUF Panel***

Expanded Polystyrene (EPS) Panel comprises of pre-fabricated composite sandwich panels with Expanded Polystyrene (EPS) insulation as core and profiled/plain, colour coated galvanized Steel/ galvalume steel sheet facing on both sides, complete with joint sealants and fixing ancillaries. Expanded Polystyrene is a lightweight closed cell rigid insulation formed by the expansion of polystyrene beads. It has excellent long term thermal and moisture resistance. EPS insulation is reliable, cost effective and compatible with major construction materials.

Polyurethane (PUF) Sandwich Panel is an upgraded material compare to traditional building material, as a kind of new type of multifunctional building material. It consists of steel plate at both side and polyurethane core of different densities inside. They are bonded with high intension adhesive at high temperature and pressure through auto forming machine.

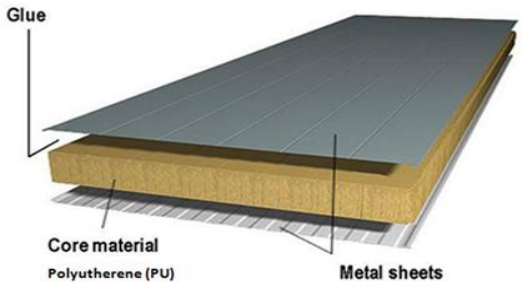

Fig: PUF Panel

Figure: EPS Panel

a) ***Thickness Availability:***

40 mm, 50 mm, 75 mm, 100 mm, 125 mm, 150 mm, 175 mm, 200 mm.

b) ***Benefits of EPS & PUF Panel:***

- Pre-engineered and factory made for precision.
- Internationally accepted and meets or exceeds all building code specifications.
- Higher energy savings due to very low thermal conductivity.
- Flexibility in design and choosing various options on fascia of panels and colors.
- All weather proof construction and maintenance free.
- Long lasting value with controlled quality, accuracy & speed of construction and caters for better functionality and application.

8) ***Dry Wall System***

This system is made of durable galvanized steel, which usually uses gypsum board and calcium silicate board or FCB (Fiber Cement Board) as surface material. Compared with wooden board, *Dry wall system* provides safer and resistive wall. Besides that, compared with bulky brick wall, it can greatly reduce the weight of building. In this system, thermal and acoustic insulation product can also be filled in partition frame to create a safe and quiet environment.

Thickness availability:

50mm, 60mm, 75mm, 90mm, 120mm, 150mm, 180mm & 210mm.

9) ***Aerated Cement Panel***

Solid cement wall systems comprised of a variety of shapes and wall types. We deal with:

Solid wall panel simply refers to walls made of solid concrete. These wall systems require some form of insulation and an interior wall finishing system to complete the building enclosures.

Cement Sandwich panel is a series of building material with fly ash, different polymer beads and sand compound as core material along with

low alkali sulphoaluminate cement and calcium silicate board as face panels.

Fig: Aerated Cement Sandwich Panel

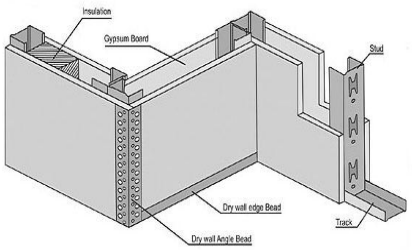

Fig: Dry-Wall System

Fig: Aerated Solid Cement Panel

Thickness Availability:

50mm, 60mm, 75mm, 90mm, 100 mm, 120mm, 150mm, 180mm & 210mm.

D. Roof Options

- PUF Corrugated Panel
- EPS Corrugated Panel
- CGI sheets
- UPVC roof
- Asphalt shingles
- Color Coated Galvalume Sheets

E. Wall Options

- PUF Sandwich Panel
- EPS Sandwich Panel
- Solid Cement wall Panel
- Dry Wall System using cement boards
- Different claddings/siding materials

F. Floor Options

Generally, cemented solid sheets are used as the flooring materials. Plywood, wooden planks, Marbles, tiles are also the options of flooring.

G. Door and Window's Frame

Hollow metal frames are very good replacement for wooden door/window frames. It can also be provided the looks of a wood frame at a very economical price and have other advantages over wood. The frames are termite proof and weather proof and have a better surface finish than wood. It can be provided with wooden shutters or hollow metal shutter or glass shutter. The shutter can also be provided with rock wool, mineral wool, PUF, Ceramic wool or polystyrene insulation.

Fig: Door and Window

H. Why Steel?

1) ***Material Cost Savings:*** Steel is cheaper in comparison of weight/strength ratio; and is ideal for building seismic-activity resistant housing.
2) ***Labor Cost Saving:*** A labor of six men can construct a steel container house within a day.
3) ***Better Safety:*** Steel's ductility allows it to stretch between 5-7% of its original length; which makes it more withstanding during earthquakes and also absorb wind turbulence due to its ductility.
4) ***Low Transport Cost:*** Steel can even be transported by people.
5) ***Time Savings:*** Due to the pre-fabricated nature of steel framing; it can be constructed at a factory and be delivered ready to erect; also no welding required on the site; the structures can be totally completed with nuts and bolts.
6) ***Lower Insurance Premium:*** Due to steel's insect, wind, and earthquake resistance, home owner's insurance premium will be much lower.
7) ***Versatility:*** Due to the standard shape of steel container they can be easily customized; extend upon and taken apart.
8) ***Eco-Friendly:*** 50 trees are needed to build the average house. In comparison steel is extracted, is recyclable in the future and minimizes wastage through customized building.
9) ***Short-Term Accommodation:*** Many European countries and military bases are utilizing the quick to construct and de-construct nature of such housing, and offering it as affordable short term housing.

I. Design Procedure

The steel beams, columns, rafter, z-purlins, channel gables, channel walls, etc. are the components of steel buildings.Following are the steps to construct prefabricated steel buildings.

1. Establishment of temporary store
2. Transportation of materials
3. Site clearance
4. Marking
5. Positioning of central coordinate and layout
6. General excavation
7. Preparation of foundation base
8. Concreting of foundation
9. Curing
10. Erection
11. Flooring
12. Roofing
13. Panel fitting
14. Installation of doors and windows
15. Electric and sanitary work
16. Finishing

Fig: Complete Steel Frame

IV. DISCUSSION

From the studies and research performed in the prefabricated materials and prefabricated structures, it is found that these prefabricated structures are very much effective in developing as well as developed countries. The construction of these types of structures saves time, money and assures the safety of the people as well. Since, these structures are light weight, earthquake resistant, and aesthetic, we can accept these structures without any hesitation. While constructing conventional buildings, time is the main factor; by just completing the concreting of one section, we cannot start another work, it should be left for about 28 days upto its curing period to allow it to gain full strength. But in these prefabricated construction there is no delay in time because most of the materials are fabricated in factory only. Since, these are earthquake resistant; these can be the best solution for the earthquake victims in Nepal. Not only for the earthquake victims, everyone replace the construction of traditional buildings and construction

V. CONCLUSIONS

- The use of prefabrication and preassembly is estimated to have almost doubled in the last 15 years, increasing by 86%.
- Earthquake resistant structures can be constructed with low investment and less time.
- The use prefab materials obviously reduce the waste produced in sites.
- Environmental risks are reduced.
- Number of labor can be reduced.
- Worker can assure their safety.

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