Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Prediction of Cost Fluctuations in Residential RC Buildings due to Seismic Non-Compliance

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Abstract

In Nepal, reinforced concrete buildings are being built at a very fast rate. The majority of buildings are being built without the guidance of a technical supervisor since engineers and architects are only allowed to do design and drafting work. The municipal engineer only verified that the plinth area, column rebar number, and diameter complied with municipal drawings; however, other details such as concrete mix proportion, bar development length, bar curtailment in beams and columns, foundation depth, hook length, foundation size, mortar in walls, and other detailing were left unchecked. Majorly, clients are persistent in economizing the cost which led to that non-compliance. The study has been conducted to predict the cost fluctuation in the residential RC buildings due to seismic non-compliance. For that work initially what aspects of construction were majorly seen as non-compliance were listed along with the details of the structural as well as non-structural component. A total of 60 sites were selected from Kathmandu district based on random sampling and availability of site. Checklist survey along with the measurement of structural members, non-complied aspects of building, causes of non-compliance was also enlisted. All those non-compliance issues are later on demonstrated as percentages. A typical architecture building was taken, analysed, designed using ET-ABS and drawn in Auto-Cad for the reference as compliance and non-compliance check during site visit. A standard estimate was done for the typical building using District rate 2078-79, also the cost incurred due to major non-compliance was also estimated for the same typical building and compared. The prediction of nature of cost fluctuation has been done through graph.

Keywords

Construction, Residential RC Buildings, Aspects of Non-compliance, Typical Estimate, Comparison

1. Introduction

Among all natural hazards, earthquake is the greatest threat to this built structured environment only because they are unpredictable about time place and the intensity with which it strikes. Being situated in such a risky zone, engineering construction has not been widely practiced. Reinforced construction (RC) was introduced in Nepal in around the 1980s, the essence of technical expertise was recognized only after the introduction of NBC in 2006. About 70% of the RC constructions are either owner-built or built as per the Mandatory Rule of Thumb (MRT)[1]. Due to the lack of construction and design philosophy introduced in the construction, those buildings are vulnerable in the time of lateral loads. The use of modern materials does not signify the changes in the trend of construction, it must be in designs, and analysis using NBC also constructed by the designs and working drawings verified by technical expertise. The growing revolution in the field of construction of all types of RC buildings started from the massive earthquake on the 25th of April 2015 with a magnitude of 7.6. The epicenter of that earthquake was 77 KMs NW of Kathmandu near the border of Lamjung and Gorkha. The vibration lasting for about 50 seconds also shook the confidence of the public towards the weaker RC buildings. Municipalities reformed their bye-laws, MRT, and gave priority to wider open spaces, lesser ground coverage, etc. As of now new NBC has been published and has been implemented in various municipalities and all other local governing bodies are on the verge of implementing NBC sooner or later. All of the responsible citizens, as well as concerned bodies, have come to know that earthquakes are not lethal, but weaker structures are. The Local-level governing bodies have made compulsions in the application of NBC during the design and analysis phase of any kind of building whether RC or steel-structured. The need for municipality-approved drawings for loan disbursement from financial institutions has made the smooth enactment of NBC easier. Although, drawings have been made compulsion its their compliance during the construction has not been fully supervised. The concerned authority visits the site only during a certain phase of construction which to some extent encourages the clients and contractors to go out of drawing and non-comply the structural details majorly. So this article depicts the issues regarding non-compliance and the degree to which the various issues are non-complied. Secondly, the major objective of this study is to find the extent to which cost can vary due to the seismic non-compliance of residential RC buildings during construction.

2. Literature Review

Nepal national building code (NBC) was first drafted in 1994. Before this in1988 massive earthquake of M6.8 hit Nepal and killed more than 700 people. People came to know the importance of a guiding building code so NBC 1994 was formulated. That draft NBC in 1994 was approved by the government in 2003 and became the legally binding document in all the municipalities. But they could not implement NBC in the village development committee (VDC) because of the difficulties of implementing regulations in villages. Since there is a lack of resources and monitoring of all those implemented codes, it has not been fully enforced. For normal residential buildings, NBC 201 and NBC 205 stipulate MRT is widely used. Now, after the 2015 earthquake of M7.8 NBC has been updated and the new NBC 2020 has been enforced to make safe all kinds of buildings like RC, steel structures, masonry structures, etc and the updated NBC has made the buildings more earthquake resilient [2]. As the trend inside the valley is of constructing RC structures, the update NBC has come as a boon. It has reformed ductile detailing, and sizes of structural members. RC building construction in Nepal started mainly after mid 90s and mainly inside Kathmandu valley. [3] recently formulated the taxonomy and vulnerability of Nepali residential buildings and they placed medium to high rise RC buildings under the D-E vulnerability class per EMS-98 vulnerability classification system. Post-earthquake damage study and validation efforts are crucial to understanding the behavior of RC structures under lateral load. Post-earthquake damage assessment in Chile, Spain, and Italy concluded that less than 10% were damaged due to the incapability of structural members to distribute damage. The seismic damage assessment of buildings inside valley concluded that the damages was mostly due to the lack of quality materials and improper ductile detailing and construction practices.

2.1 Past Studies

Common structural and construction deficiencies of Nepalese Building revealed after the study showed the various issues and deficiencies causing the structural failure of the buildings in the Gorkha Earthquake 2015: some of the issues were soft story, longitudinal reinforcement detailing, floating columns, concrete mixing and placement, load asymmetry, building interaction etc[1]. In Karyabinayak Municipality has been taken as a site for case study of compliance of building code, the aspects of non-compliance and its issues regarding has been considered[4]. As we have mentioned, building codes first began in order to prevent and protect against community disasters. The number of natural disasters continues to grow each year, including at least 207 worldwide during the first half of 2020 (above the past decade's average of 185). Building codes will be as important as ever as we seek to continually improve upon them to help safeguard against the increase in dangerous fires, earthquakes, and more.

2.2 Building practices and trends

With the ever-growing population of Kathmandu valley, the trend and demand of residential accommodation have a significant rise. There are numerous buildings built and numerous are being built. For the past 2 decades, the trend in the housing industry has skyrocketed. Initially, the idea of residential buildings inside Kathmandu valley was only for higher strata of society. As time progressed, everyone sought their own house inside the valley which rose the construction of residential buildings over the past decade. The financial institutions also facilitated real estate. Clients were only concerned about the house being built, not its seismic vulnerability. They cared about building a house as cheaper as possible. So, they along with the local governing body did not focus on making it durable and safer until the 2015 earthquake. After the earthquake numerous pieces of research were done that showed the deficiencies in various aspects that made that earthquake lethal.

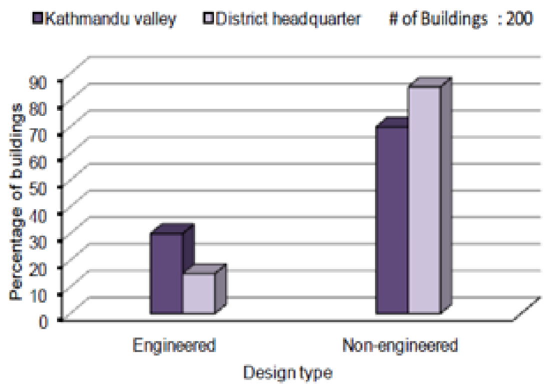

Figure 1: Distribution of % of buildings according to design type

However, those stereotypical views have changed regarding the non-compliance of building codes during construction attracting people from all walks of life to follow the various set of rules. The government has set a standard for the building materials that building companies. After the 2015 earthquake, there was prevalent damage to various non-complied buildings of the valley. All the major damages were due to the insufficiency of the reinforcement works, which was ultimately due to the money factor.

2.3 Ductility

Ductile detailing is provided in structures so as to give them adequate toughness and ductility to resist severe earthquake shocks without collapse. Among various zones for ductile detailing, Nepal lies in seismic zone V which creates the necessity for ductile detailing during construction.

2.4 Compliance parameter

As per the reference from the case study in Karyabinayak Municipality, the compliance , following parameters were considered[4]:

- Configuration check.
- Strength Check.
- Ductility check.
- Connection check
- Earthquake safety features (ties, lap length etc.)

2.5 Effectiveness of implementation

There is a clear distinction between enforcement through control and compliance at the top level of the pyramid. In terms of both effectiveness and compliance, the former is more likely to be achieved at the bottom level[5].

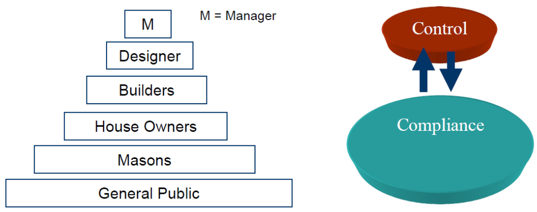

Figure 2: Compliance vs control

3. Research Methodology

3.1 Study area

As the common buildings are numerous, so the study area is main targeted in areas with rapid urbanization where the chances of non-conformity with the NBCs are found in greater extent.

3.2 Site selection

The sites are selected and visited inside Kathmandu district. Sampling was carried out from ongoing construction sites only.

3.3 Data collection

3.3.1 Checklist survey

For proper data collection and better outcomes, a checklist should be prepared so that no aspects of this will be missed. It involves:

- Location of building
- Characterstics of mason
- Strength related questions
- Ductility related questions
- Causes of non-conformity with drawings

3.3.2 Interview

To fill all those checklists, an interview will be carried out with the site in charge to greater extent as possible. In case of local contractors, he/she shall be interviewed directly.

3.4 Population and sample size

For 90% confidence level with 10% confidence interval, Using the cochrans formula sample size was determined. The final data collected as the sample was 60.

3.5 Pilot test

Pilot test was done and improvised checklists was prepared for larger scale of the study.

3.5.1 Tools for analysis

Initially, a typical house was designed using IS code and NBC 2020. All the required drawings were drawn i.e. from footing to slab of a floor. The designed building was an architecture building of a municipality in the Kathmandu district. All the major non-compliance issues were extracted from the site visit. The major non-compliances were later generalized and estimated using the district rate for the same building that was designed using NBC and IS code. Excel is a commonly used tool for calculating the non-compliance amount and percentage of buildings. It can also be used to estimate the variance between the complied and non-compliant buildings. Finally, after cost estimation of complied building and non-complied building with the various issues, graphs was plotted for prediction of cost fluctuation.

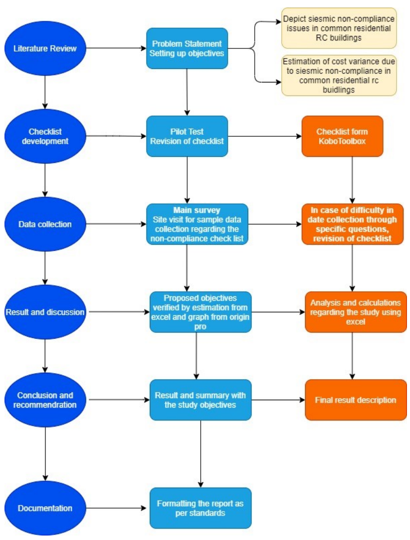

Figure 3: Methodology flowchart

4. Data Analysis and Discussion

The frequency and percentage of these numbers will be shown in a chart and table

Table 1: Trend of construction with contractors

S.No	Type	Frequency	Percentage
1	Contractor built without engineer as supervisor	53	88.33
2	Contractor built with engineer as full time supervisor	7	11.67
	Total	60	100

Among 60 samples 88.33% of the sample were contractor built without the supervision of an expert. From non-engineered, owner-built houses being prevalent to contractor-built being the case, the trend has changed.

Table 2: Degree of compliance

S.No	Description	Compliance	Non-Compliance
1	Depth of excavation	60	-
2	Foundation		
a	Depth	8	-
b	Rebar	8	-
c	Strap beam	6	2
3	Column size	60	-
4	Beam size		
a	Foundation beam	52	-
b	Plinth beam	52	-
c	Main beam	52	-
5	Slab thickness	52	-
6	Clear cover		
a	Foundation	8	-
b	Beam	52	-
c	Column	52	-
d	Slab	52	-
7	Reinforcement		
a	Foundation	8	-
b	Column	17	13
c	Beam	19	4
d	Slab	22	-
8	Stirrups	32	20
9	Lap length	12	33
10	Hook length	30	22
11	Exterior wall	15	15

In summary, 100% compliance has been seen in the size of structural members while major non-compliances were in rebars of all the structural members. Sample sizes of the various structural members are different because of the availability of the data during the site visit. The size of structural members can be verified during any stage of construction while for the rebars, the sample number is less because of the lesser rebar works seen during site visit. For example, column size can be verified even after the completion of the building but column's rebar sample is lesser as only 30 sites had the column works being done. Other major non-compliance were hook length, lap length, stirrups, ties and external walls with their non-compliance percentage being 42.3%, 73.33%, 38.46%, 50% respectively. Compliance for beam, column and slab are represented in figure below respectively.

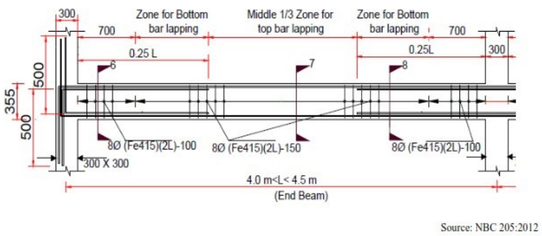

Figure 4: Beam splicing

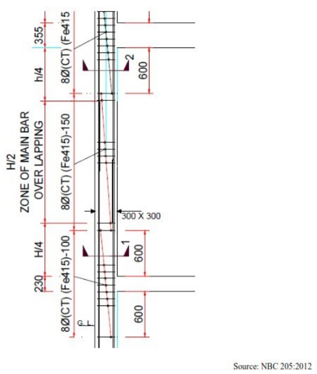

Figure 5: Column beam joint

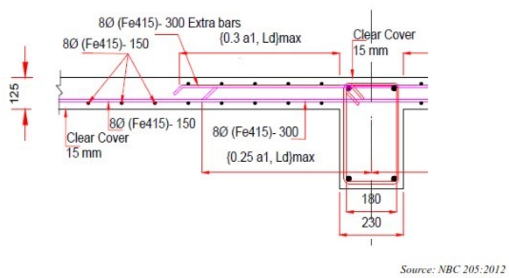

Figure 6: Slab beam joint

4.1 Estimation due to compliances of all aspects

Table 3: Complied estimate using district rate

Description	Unit	Quantity	Rate	Total
Excavation	m^3	101	749	75648
Back filling	m^3	60	704	42180
PCC	m^3	21	13195	277095
Brick soling	m^3	105	1109	116445
Foundation	m^3			453962
Foundation beam	m			183054
Strap beam	m			183054
Toe wall	m	12	15865	190380
Tie beam	m	51	6143	313293
Column	nos	12	18312	219746
Main beam	m	51	3726	190026
Slab concrete	m^3	8	19709	157672
Slab rebar	kg	1132	136.83	155084
Formwork in slab	sq.m	74	1517	112258
Exterior wall	m^3	8	15865	126920
Partition wall	m^3	4	15865	63460
	Total			2902058

This table is calculated after the measurement from structural drawings of typical drawings designed using latest NBC. Here, the total cost is because of all the members considered complying with NBC and structural drawing. The total cost of non-complied building till ground floor excluding the finishing cost totaled to twenty nine lakh two thousand fifty eight rupess only. This cost comprised of strap beam present but rebar non-complied. There were two kinds of non-compliance in strap beam:

- Strap being is present but the rebars have not complied during the construction
- Omission of strap beam

This estimate is because of the strap beam with non-complied rebars

Table 4: Non-complied estimate using district rate

Description	Unit	Quantity	Rate	Total
Excavation	m^3	101	749	75649
Back filling	m^3	60	703	42180
PCC	m^3	21	13195	277095
Brick soling	m^3	105	1109	116445
Foundation	m^3			446352
Foundation beam	m			183528
Strap beam	m			144308
Toe wall	m	12	15865	190380
Tie beam	m	51	5167	263517
Column	nos	12	16720	200640
Main beam	m	51	3726	190026
Slab concrete	m^3	8.48	19709	157672
Slab rebar	kg	1132	137	155084
Formwork in slab	sq.m	74	1517	112258
Exterior wall interior wall	m^3	11	15865	174515
	Total			2729649

The total cost of non-complied building till ground floor excluding the finishing cost totaled to Twenty seven lakh twenty nine thousand six hundred and forty nine rupees only. This cost comprised of strap beam present but rebar non-complied. There were two kinds of non-compliance in strap beam:

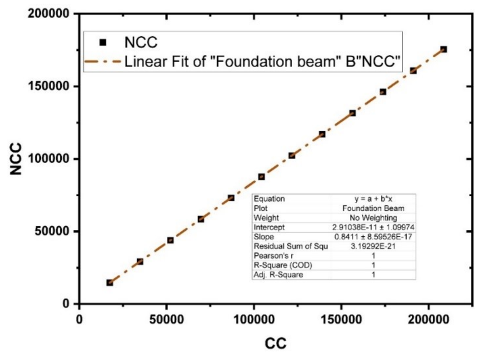

Figure 7: Linear fit of foundation beam

This is a calibration curve plotted complied foundation beam versus non-complied foundation beam. The graph is a perfect linear because cost of twelve non-complied foundation beam is twelve times the cost of single non-complied foundation beam.

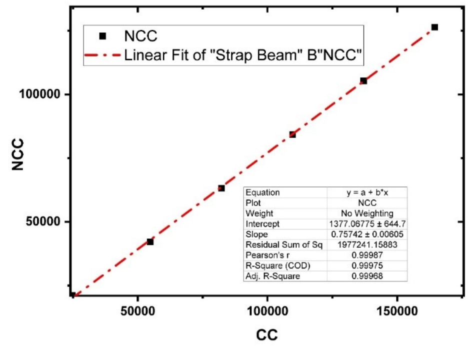

Figure 8: Linear fit of strap beam

This is a calibration curve plotted costs of complied strap beam versus the cost of non-complied strap beam costs. This curve is also a perfect linear as cost of six strap beams are six multiple of cost of non-complied strap beam.

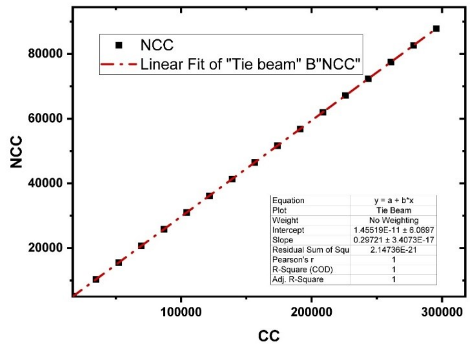

Figure 9: Linear fit of tie beam

This is a calibration curve plotted cost of complied tie beam versus the cost of non-complied tie beam. It is also a perfect linear curve as it is just like a unitary calculation.

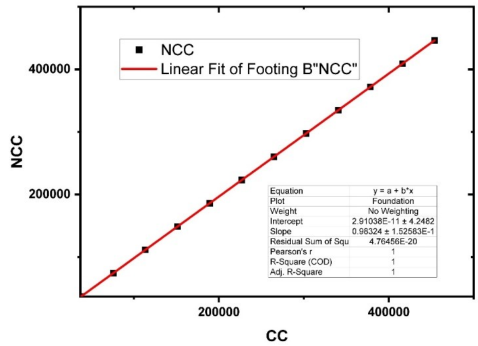

Figure 10: Linear fit of footing

This is also a calibration curve which is plotted against cost of complied footing versus the non-complied footing. All calibration curves are a perfect linear as cost of complied as well as non complied components increase linearly as number gradually increases.

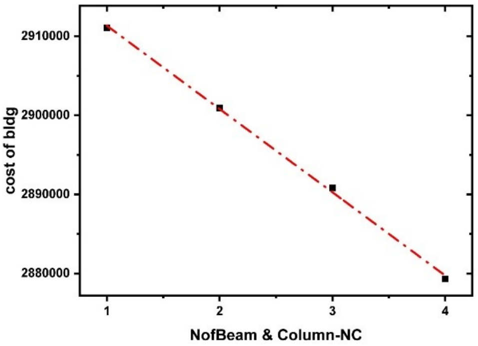

Figure 11: Non-complied beams and columns cost vs Total cost of building when complied

This is a curve plotted total cost of building when complied against the combination of beams and columns non-complied in certain percentage. The combination of non-complied beams and columns are 25%, 50%, 75% and 100% of total numbers respectively. Due to unequal numbers of beam and column, their combination is considered and its cost fluctuation slightly deviated from linear graph.

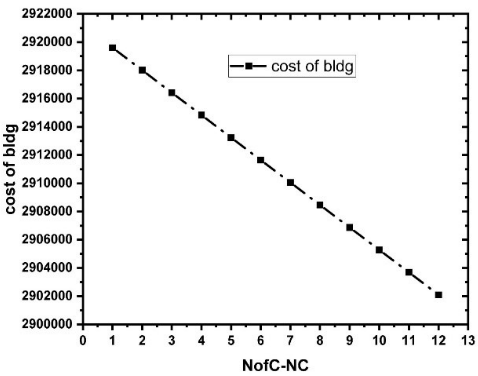

Figure 12: Non-complied columns cost vs Total cost of building when complied

This is a curve plotted cost of building when complied against numbers of beams non-complied and their cost fluctuations can be seen on the curve. The cost deductions due to their non-compliance is gradual.

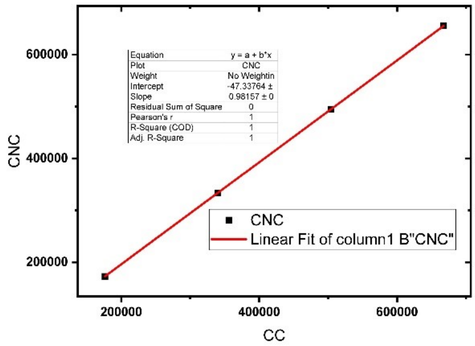

Figure 13: Non-complied beams and footings cost vs Total cost of building when complied

This curve is plotted between a combination of beams and footings in percentage (25%, 50%, 75%, 100%) of their total numbers. 25% of total beams and footings accounted in cost deduction is in left most side while the 100% non-compliance accounted is shown of top right side of the curve.

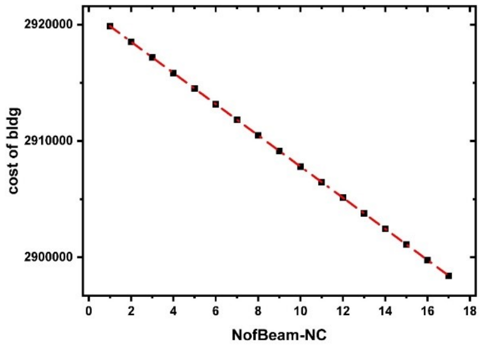

Figure 14: Non-complied beam cost vs Total cost of building when complied

This curve depicts the cost deductions due to non-complied beams when compared to complied costs. The curves here shows the cost deduction tendency as non-compliances seen on sample sites were meant to reduce the costs

5. Conclusions and Recommendations

5.1 Conclusions

The study on construction seismic compliance of residential building inside Kathmandu District. Checklist survey with inspections, site measurements, inquiry with the local contractors was carried for the under-construction buildings. The quantity of non-compliant building drawings entering the municipality suggests a pressing need for the implementation authorities as well as the capacity building of engineers and sub-engineers. In this situation, it would appear necessary to provide training for various levels of engineers for various classes of buildings. The outcomes of research objectives were found as follows

Objective one: Depiction of common seismic non-compliance issues in common residential RC buildings. The study showed the following regarding the non-compliance:

- None of the buildings complied fully with the design drawing.
- 100% compliance was found in depth of excavation, clear cover, sizes of structural members like footing, beams, columns and slabs
- Major degree of non-compliance was found in sizes of rebars in all members, omission of strap beams, lap positions, lap length, hook lengths and external wall thickness.

Objective two: Estimation of cost variation due to seismic non-compliance in residential RC buildings. The cost deduction due to various non-compliance when studied individually were seen linear. The combination of non-compliances was slightly different than the individual ones. Due to non-compliance the cost is seen to have been reduced to some extent. The graphs plotted on complied columns vs non-complied columns has shown a linear relationship along with the complied vs non-complied strap beams, foundation beams, main beams, etc.

5.2 Limitations

The followings are the potential limitations regarding the research:

- The analysis of verified drawings are not done.
- The sample is constricted to RC residential buildings inside Kathmandu district
- Major non-compliance are taken which were seen visible during the site visit. The major non-compliance as per previous research i.e. mix proportion is not considered.

5.3 Recommendations for further study

- Similar study can be conducted in other municipalities
- For enough samples, this can be studied in mid-rise and high-rise RC structures as well.
- Steel structures can be considered for similar study
- This study can be done considering other non-compliances prevalent during construction.

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