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Footprint of construction errors on the structural damages

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ABSTRACT

The majority of structural failures are attributable to errors in construction. This problem exists in all countries, but it is more frequent in developing communities. This study focuses on construction errors of structures in Tehran, the capital city of Iran. In this study, eighty-eight buildings have been investigated during the construction phase. These buildings have been categorized into ten types and have been distributed in twenty-two suburbs. Results showed that the buildings of Tehran can suffer from at least forty-nine major construction problems. In addition, for the first time, this research has introduced the following three terms in relation to prioritizing of construction errors: Relative Importance Factor (RIF), Priority Index (PI) and Structural Importance Index (SII). As a part of the conclusions, the results showed one hundred percent of investigated buildings are affected dramatically by the "use of untrained workers" and "lack of sampling or wrong sampling" too. In this regard, the RIF and PI of each "Lack of sampling or wrong sampling" and "use of untrained workers" are 100 and 1, respectively. Also, suburb 3 has the best construction conditions while suburb 10 has the worst.

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1. Introduction

Most of the construction mistakes may not lead to immediate collapse, but they may have an adverse impact on the structures over time (Tahmoorian, 2017). A lot of research work has been undertaken in this regard. For example, Knyziak (2019) conferred a safety analysis of structures in the context of building collapses as a result of exceptional loads and in the context of their technical condition. He explained examples of incorrect construction and maintenance from on-site inspections of 110 structures in Poland. Improper structural assembly, not corrosion protected elements, elements damaged in the construction phase, no repairs after exceptional loads, and lack of retrofitting are discussed. Bayoumi et al. (2019) identified and evaluated the construction mistakes during the implementation of concrete T-beams. Their study was borne out of the need to investigate some of the many factors responsible for the failure of structures, like the impact of misplacement of slab steel bars and the effect of the irregular arrangement of steel bars and change in their size on the structural performance of T-beams. It is suggested that a high level of quality assurance be maintained during the construction process. Peng et al. (2019) explored construction safety, taking the steel-reinforced concrete (SRC) structure collapse incident of a new factory under construction in Taiwan as an example. In addition, the analysis results of a simplified composite column further reveal the differences between the SRC structure construction procedure and the steel structures (SS) structure construction procedure. Therefore, in order to prevent the SRC structure from collapsing during construction, proper designs and safe assembly procedures for SRC structures should be formulated to perfectly match the assembly procedure of the steel frame with that of the RC part. Galvao et al. (2018) identified the construction errors that represent a higher risk for reinforced concrete bridges.

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They developed a human error survey together with design and construction experts on this subject, to collect and assess these errors by using risk-based indicators (probability of occurrence and consequences). The corresponding survey results are analysed by using a decision-making tool, named the Analytic Hierarchy Process (AHP), which will allow the identification of the errors with higher consequences and a higher probability of occurrence. Based on this survey, a qualitative risk-based evaluation of the errors is also performed.

Brown et al. (1988) attempted to review selected research on structural engineering mistakes. They discovered the relationship between mistakes and aspects of professional life and education. Two hundred and seventy-five cases of errors in concrete structures were reported in a survey of consulting engineers and government agencies in North America conducted by ACI Committee 348. About one-half of the errors originated at the design phase and the other half occurred during construction, with each phase responsible for about the same number of collapses (Fraczek, 1977). In a similar study run by Allen (1979), one hundred and eighty-eight cases of error in concrete structures with 29 resulting in collapse and 118 in distress, deterioration, excessive cracking, spalling, deflection, or settlement, were collected across Canada. The survey indicated that about half the errors originated at the design and the other half were due to faulty construction. HaydI et al. (2000) discussed three examples of construction failures. They concluded that many types of construction failure can be avoided by employing better engineering practices in design and construction. Other researchers (Dziurawiec et al., 1986) studied construction errors and perceptual difficulties encountered in reading technical drawings. Also, Chen et al. (2007) studied the effect of changing the sloping angles of arch ribs of a bridge and their displacement due to construction errors on the stability factors of the structure under dead load and dead plus live loads for 10 load cases. Reichart (1988) explained how to reduce construction errors. In his paper, an attempt is made to develop a framework of methods, which can help to reduce construction mistakes. Based on the idea that human errors are mainly errors due to the lack, non-use or misapplication of information, methods for the assurance of completeness, use and correct application of design are proposed. Riemer (1976) showed much of the damage and added cost created by construction mistakes is manageable. On the other hand, Gonzalez et al. (1986) introduced a method for evaluation of nuclear reactor seismic risk due to construction and design mistakes based on deficiencies identified in the past. The application of the method is described based on a limited review of data, showing its capabilities and limitations. Tahmoorian & Khabbaz (2020) presented a settlement prediction method of municipal solid waste (MSW) landfills to estimate and control structural damages. They have explained all engineering and construction factors which are involved in this field. These researchers also in other reports, reviewed the structure performance of recycled materials (Tahmoorian et al., 2019 and 2020a) and tools (Tahmoorian et al., 2020b) in the construction and service phases.

2. Methodology

Tehran, the capital city of Iran with a population of 15,830,000 people is located in a seismic prone zone with an approximate density of 10,327 people/km^2 (in comparison to 380 people/km^2 for Sydney). The high population density and the presence of numerous active faults in Tehran have caused a national catastrophe resulting from each devastating earthquake. On the other hand, limited funding for the structures rehabilitation in Tehran has led to confusion among officials about prioritizing and adopting an appropriate rehabilitation regime. Therefore, study on the prioritization of buildings and the identification of executive problems can reduce the mortality and financial losses after a possible earthquake in Tehran. This study investigated the construction errors of 88 building structures in twenty-two suburbs of Tehran (Fig. 1).

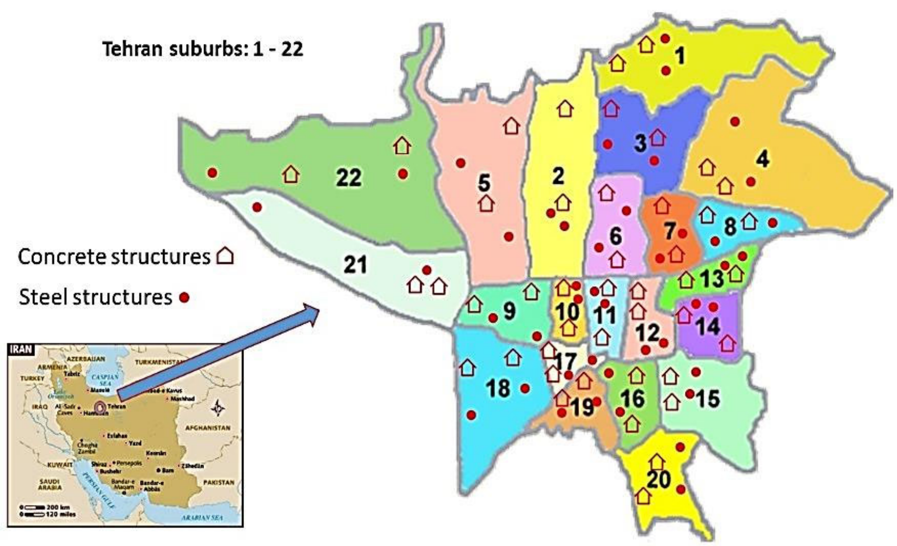

Fig. 1. Types, abundance, and distribution of samples in Tehran region.

The quality of construction varies by the suburbs in Tehran. "Worn regions" can be considered as a significant reason for this difference. Based on a known definition, more than 50% of buildings in the worn regions do not have any structural system. In addition, more than 50% of buildings in these regions have an area smaller than 200 m^2 and are located at avenues which are narrower than 6 m. These factors, together with the economic problems of the inhabitants of these regions, make the buildings located in worn regions cheaper than the other regions. Therefore, investment in the construction in these regions is likely to be cheaper than the other ones. About 5% of Tehran areas are recognized as "worn regions" which are mostly located at suburbs 7, 10, 11, 12, 13, 14, 15 and 17 (ISUDO, 2019). On the other hand, regional councils have different local policies for quality control of structures. Subsequently, the quality level of buildings in some of the suburbs is a little higher than the other suburbs. In this regard, two steel structures and two concrete structures are investigated at all suburbs. Studied buildings have been categorized to three types based on Iranian civil engineers' registration rules (IRCEO, 2019) which are distributed in Tehran with a normal Samples Statistical Distribution (SSD) (Table 1).

Table 1. Categories of studied buildings in Tehran region (IRCEO, 2019)

Category	1	2	3
Number of floors	1 - 2	3 - 10	11 - 20

Referring to the Iran Statistics Yearbook 2017 (SCI 2018), categories 1, 2 and 3 cover 8.5%, 71% and 20.5% of under-construction buildings in Tehran. On the other hand, steel structures and concrete structures include 99.9% of Tehran buildings. This rate would be reduced to 81.5% across Iran. Also, the number of concrete structures in Tehran is almost 2.4 times that of steel structures in this city. Therefore, study on steel/concrete structures in Tehran is more important than the other areas of Iran. In this study, at least one sample of each category has been investigated at any suburb. Twenty-two trained civil engineering students, one lecturer and eleven professional engineers have been involved in the inspection process of this research for over two years. The inspectors carried out some visual checks based on standard inspection forms and checklists such as "Construction Safety Checklist" (Nemati & Lahooti 2016).

3. Categories of construction errors

Recognised construction errors can be identified as seven major categories including "use of weak concrete" including, "use of weak materials", "use of unsuitable details", "use of weak connections", "wrong dimensions and positions", "Foundation problems" and "HSE (Health, Safety and Environment) problems".

3.1. Use of weak concrete

Anyconcrete element regardless of its importance, size and position, must have aproper mix design. However, 80% of steel structures (SS) and 70% of concretestructures (CS) do not have a real and reliable mix design. In these cases, concrete(or even ready-mixed concrete) usually have been made based on traditionalmethods and practices. Also, the concrete is still made often by hand. Theincorrect mixing of concrete components is one of the major problems of suchbuildings. In addition, the concrete casting method in 80% of steel structuresand 70% of concrete structures is wrong. Casting by shovel, discharge by chutefrom high altitude and concrete distributions by vibrator are among some of thecommon errors. On the other hand, in almost all cases, concrete vibration hasbeen associated with some errors such as inadequate vibration, over vibration, inadequatedepth of vibration, duplicate vibration, close vibration, pushing andnon-overlapped vibration. Also, any concrete element needs to be cured by waterin order to complete chemical reactions. However, 42% of concrete elements in concretestructural elements (such as diaphragms) and 95% of whole Concrete buildingshave not been adequately cured. Generally speaking, concrete casting in adverseweather conditions may reduce the concrete strength. However, some arrangementscan be made in order to cast in weather conditions. Surprisingly, in somecases, the concrete casting was done in snowy and sub-zero temperatureconditions. Also, in spite of the importance of conducting concrete tests, inmore than 95% of the studied cases, a reliable concrete test was not carriedout. Because the minimum required number of samples, the sampling method andthe period of sampling were not at all acceptable. Unfortunately, many expectmiraculous behaviour from shotcreting. For this reason, shortcrete-made structuresare not often completed. Insufficient cover, up to down shotting direction andneglected supports are the most common construction errors in investigatedcases (Fig. 2).

Fig. 2. Not completed shotcrete structures

Choosing the right place for construction joints is critical in the strength of resulting concrete elements. Unfortunately, this study showed there is a structural weakness in at least 41% of steel structures and 11% of concrete structures due to unsuitable construction joints (Fig. 3).

Fig. 3. Wrong construction join position at a concrete wall joint (left) and a shear wall (right)

One of the other construction errors in the investigated cases is the localized and partial removal of concrete elements without any permission (Fig. 4).

Fig. 4. Unauthorized concrete tampering and welding some architectural parts to bars

25% of concrete structures in Tehran have this problem. This error can sometimes destroy the integrity of the entire building. Also, in some cases, the required covers specified in the drawings are not provided for reinforcement steels. This error, in addition to corrosion and causing concrete cancer, can reduce the bearing capacity of some parts of the steel bars. On the other hand, construction wastes are not only used instead of spacers but also in 5% to 27% of cases; they are used as fillers in concrete structural elements.

3.2. Use of weak materials

The use of proper and standard construction materials is one of the basic rules in all codes and regulations. The correct sampling of materials is the most reliable way to ensure compliance with this principle. The observations of this study have shown that in all cases, proper sampling of materials is not performed. Based on the observations, use of substandard, pre-used (up to 34% of steel structures), stained, dirty, rusty and outside specification materials, such as steel profiles, joists, aggregates or even water, are the sources of some of these errors. For example, 95% to 100% of concrete elements of investigated buildings have been made using outside specification aggregates. Improper storage can also reduce the quality of the materials. This error is commonly occurring (up to 43%) for cement packs and prefabricated steel elements.

3.3. Use of unsuitable detailing

It is essential to use the correct technical details in order to build resistant structures. However, sometimes the details and drawings are wrongly changed during the construction phase. Intentional or unintentional human errors are the main reason for this problem. These errors can lead to "steel bars displacement and deformation (in 11% to 34% of cases)" and "weak hooks (in 11% to 18% of cases)" in structures. Another dangerous example of construction errors is a blocked disconnection joint. Subsequently, the pounding impact can lead to the destruction of the whole building during an earthquake. This error is detected in 43% of steel structures and 55% of concrete structures of Tehran. Lack of attention to the structural details of the stairs and lifts is another construction error detected in 34% to 41% of cases. Removing the wall posts of slender walls is another common error (Fig. 5). This error, which occurs in 25% to 36% of buildings, kills many people during earthquakes worldwide.

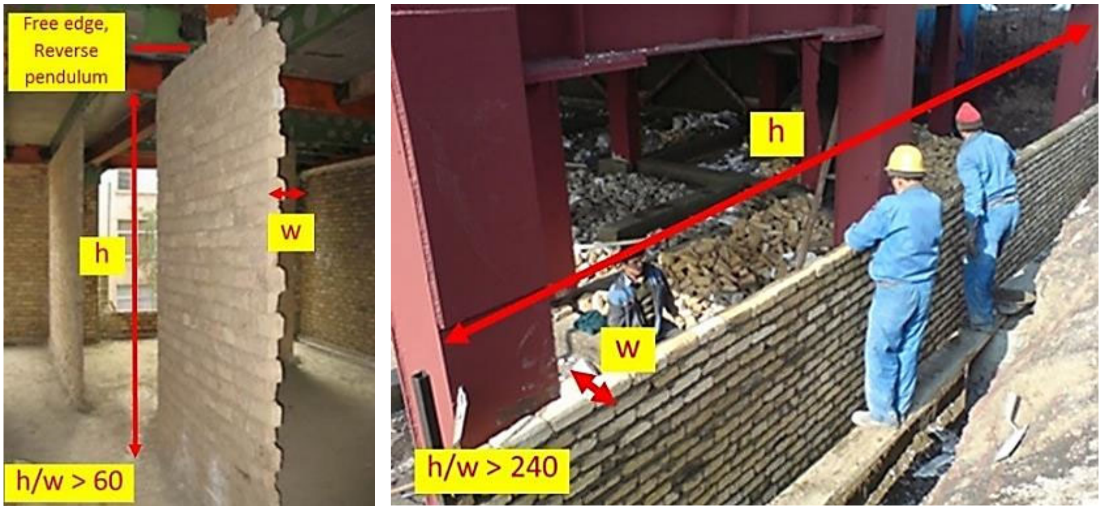

Fig. 5. Post-less slender walls

The structural system of façades in 48% of steel structures and 64% of concrete structures is also constructed inadequately. The weak welds and the use of heavy stones without any anchor-screws are among this type of construction errors. One of the errors that is rarely considered is the change of stiffness and slenderness of structural members due to the connection with non-structural elements (Fig. 6).

Fig. 6. Sudden change in the slenderness (left) and punching the columns and braces in order to pass the utility pipes (right)

The problems that arise from this issue include:

- A sudden change of stiffness and the possibility of a soft or hard storey in buildings;
- Changing the slenderness and consequently changing the bending axis and changing the three-dimensional behaviour of the structure;
- Local buckling or bearing in thin-walled steel components;
- Disturbance in the behaviour of the lateral bearing systems, such as braces.

Also, 20% of steel structures and 48% of concrete structures are subjected to loads not considered in the design. Loads of ceilings, channels, pipes and water tanks are some examples of these overloading. Improper construction details are the main reason for this problem.

3.4. Weak connections

Connections have an essential role in the stability of structures. Regardless of the correct design, proper construction also plays a vital role in the performance of connections. For example, the welded joints of tubular members should be done very carefully. However, the use of undefined or wrong connections is detected in 14% of steel structures and 5% of concrete structures in Tehran (Fig. 7).

Fig. 7. A weak welded connection of tubular members (left) and a wrong concrete connection (middle and right)

In addition to the errors mentioned above, welding on the painted surfaces as well as weak welding are two common construction errors which are detected in 11% and 68% of steel structures, respectively. Unsuitable welding polarization was one of the reasons for weak welds in some of the investigated cases. The incomplete connection is another type of common construction error which is detected in 7% of steel structures. Also, in 39% of steel structures, there are some shrimp assembled joints as well as low tension of bolts. Use of waste steel profiles to make important elements like braces is another construction error. This error can sometimes cause some bending couples in a perpendicular direction to the bracing diaphragm (Fig. 8). In addition, in 75% of steel structures welding slags are not removed. Obviously, these slags hold the water similar to foams and cause corrosion of steel over time.

Fig. 8. An example of structural issues due to construction errors in the bracing system

3.5. Wrong dimensions and positions

Twisted or non-alignment members and wrong dimensions of elements are two common types of construction errors regarding concrete structures. These errors are found in 43% to 55% of the studied cases. Some examples of these errors can be seen in Fig. 9.

Fig. 9. Some examples for non-alignment columns (left), wrong dimensions of slabs (middle) and wrong position of beams (right)

3.6. Foundation problems

Lack of geotechnical investigation and appropriate tests are detected in 91% to 93% of cases. The number of tests, samples and, reliability of them is also questionable. Hence, many buildings are built on old embedded wells or invisible water/wastewater old channels. These buildings are quite susceptible to settlement. In 11% to 25% of cases, foundation construction is performed without accurate surveying. Subsequently, off-axis foundations or weak base plates (in 32% of steel structures) are created. Also, in 11% to 20% of cases, foundations are made with low-quality concrete too.

3.7. HSE problems

Use of untrained workers is another construction error. This error was seen in all cases. This is the main reason for many other errors. "Wrong construction waste management" and "inattention to HSE concepts" which are detected in 9% and 56%

of cases, respectively, are two examples of these exacerbated errors. This would be more serious in the absence of reliable supervision. However, there is no such supervision in 80% to 86% of cases. On the other hand, inattention to HSE concepts can increase human errors due to stress in workers. Table 2 shows a summary of the observations and the Relative Importance Factor (RIF) of different errors. In Table 2, the Relative Importance Factor (RIF) for each error (%) is defined as (the number of cases with related error * 100) / (number of investigated buildings).

Table 2. The Relative Importance Factor (RIF) of different errors in concrete or steel structures, the total relative importance factor and SS/CS Priority Factor

Type of problem	Cases in Steel Structures (SS)	Relative Importance Factor (RIF) in SS (%)	Cases in Concrete Structures (CS)	Relative Importance Factor (RIF) in CS (%)	Total cases	Total Relative Importance Factor (%)	Structural Importance Index (SII)
Use of weak concrete including:		**SUM: 527**		**SUM: 493**			**1.07**
Lack of mix design	35	80	31	70	66	75	
Wrong concrete casting	27	61	38	86	65	74	
Wrong vibration	44	100	42	95	86	98	
Weak curing	42	95	41	93	83	94	
Casting in unconventional weather	2	5	3	7	5	6	
Scrimp tests	44	100	42	95	86	98	
Weak shotcrete	3	7	0	0	3	3	
Wrong construction joints	18	41	5	11	23	26	
Wrong demolition of concrete	5	11	11	25	16	18	
Un-provided cover	0	0	2	5	2	2	
Waste filled concrete	12	27	2	5	14	16	
Use of weak materials including:		SUM: 268		SUM: 280			0.96
Lack of sampling or wrong sampling	44	100	44	100	88	100	
Unsuitable storage of materials	6	14	19	43	25	28	
Use of second hand materials	15	34	2	5	17	19	
Use of nonstandard materials	2	5	4	9	6	7	
Use of stained steel	6	14	6	14	12	14	
Out of specification aggregates	43	98	44	100	87	99	
Use of dirty materials	1	2	3	7	4	5	
Use of unsuitable water	0	0	1	2	1	1	
Unsuitable welding electrode	1	2	0	0	1	1	
Use of unsuitable details including:		SUM: 241		SUM: 302			0.8
Steel bars displacement and deformation	5	11	15	34	20	23	
Weak reinforcement steel hooks	5	11	8	18	13	15	
Wrong discontinuity joints	19	43	24	55	43	49	
Wrong stair and lift details	15	34	18	41	33	38	
Use of slender walls	16	36	11	25	27	31	
Weak façade structural details	21	48	28	64	49	56	
Stiffness and slenderness changing	11	25	2	5	13	15	
Unauthorised changes of drawings	5	11	6	14	11	13	
Over loading	9	20	21	48	30	34	
Weak connections including:		SUM: 230		SUM: 11			20.9
Weak connection to tubular members	1	2	0	0	1	1	
Undefined / wrong connections	6	14	2	5	8	9	
Multi-parted bracing	3	7	0	0	3	3	
Incomplete connections	3	7	0	0	3	3	
Scrimp assembled joints	17	39	2	5	19	22	
Painted steel welding	5	11	1	2	6	7	
Inadequate tension of bolts	2	5	0	0	2	2	
Weak welding	30	68	0	0	30	34	
Scrimp welding slag removing	33	75	0	0	33	38	
Unsuitable welding polarization	1	2	0	0	1	1	
Wrong dimensions and positions		SUM: 5		SUM: 98			0.05
Twisted or nonalignment members	0	0	19	43	19	22	
Wrong dimensions of elements	2	5	24	55	26	30	
Foundation problems including:		SUM: 148		SUM: 136			1.09
Off-axis foundations	5	11	11	25	16	18	
Weak foundation	5	11	9	20	14	16	
Weak base plate	14	32	0	0	14	16	
Lack of geotechnical investigation and tests	41	93	40	91	81	92	
HSE problems including:		SUM: 245		SUM: 250			0.98
Wrong construction wastes management	4	9	4	9	8	9	
Use of untrained workers	44	100	44	100	88	100	
Scrimp supervision	35	80	38	86	73	83	
Inattention to HSE concepts	25	57	24	55	49	56	

Based on Table 2, the structural Importance Index (SII) for any type of problem could be defined as:

Structural Importance Index (SII) = Σ Relative Importance Factor (RIF) of SS (%) / Σ Relative Importance Factor (RIF) of CS (%)

Table 3 shows the Structural Importance Index (SII) of different detected problems in the studied buildings and Fig. 10 shows the related info-graphs.

Table 3. Structural Importance Index (SII) of different detected problems

Type of problem	Structural Importance Index (SII)
Use of weak concrete	1.07
Use of weak materials	0.96
Use of unsuitable details	0.8
Weak connections	20.9
Wrong dimensions and positions	0.05
Foundation problems	1.09
HSE problems	0.98

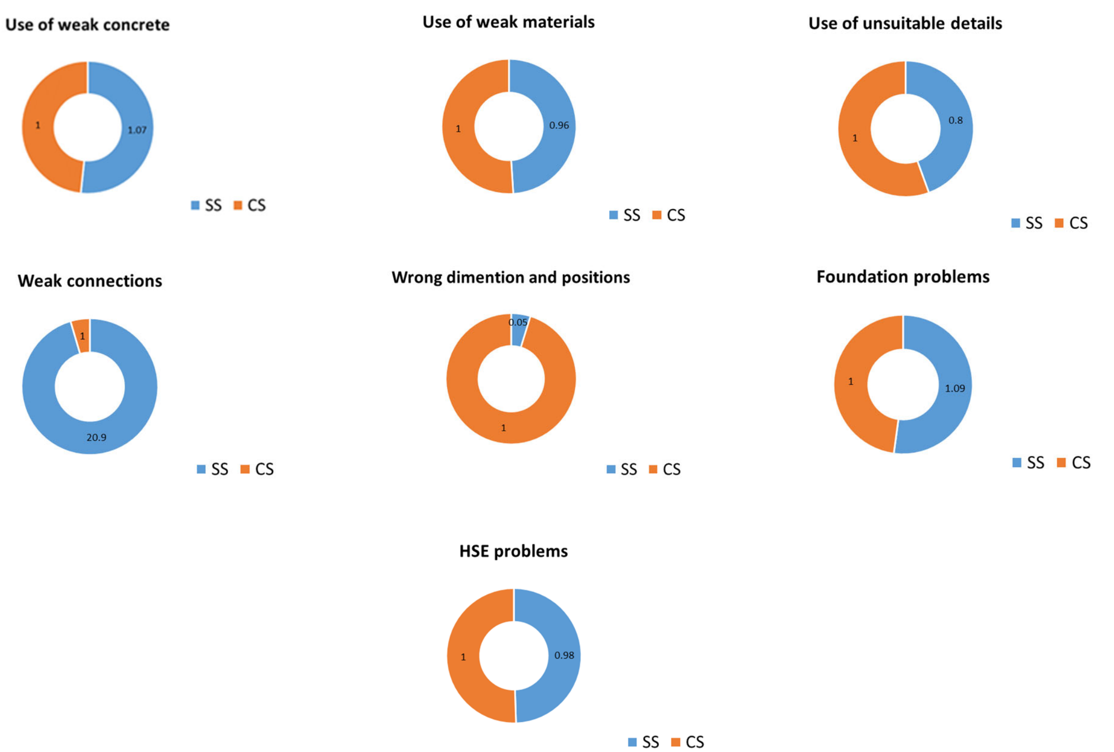

Fig. 10. Info-graphs of several construction errors in Tehran

Fig. 11 shows the sorted total relative importance factor (RIF) of several construction errors in Tehran construction sites.

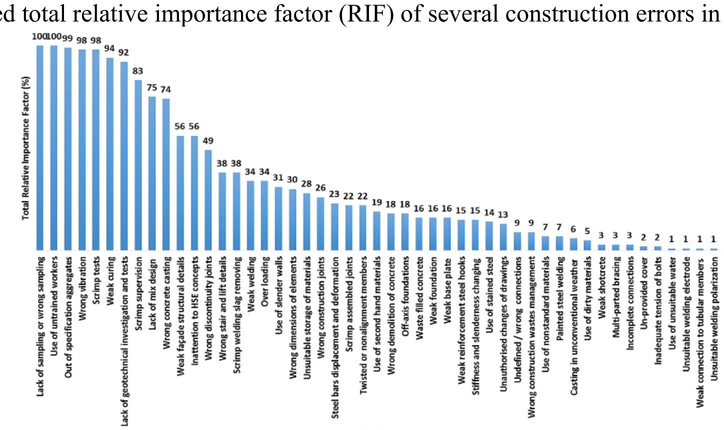

Fig. 11. Total Relative Importance Factor (RIF) of several construction errors in Tehran

Accordingly, a rating system of 1 to 10 is defined as “Priority Index (PI)”. In this system:

if 1≤ RIF≤ 9 then PI=10;
if 10 ≤ RIF≤ 19 then PI=9;
if 20 ≤ RIF≤ 29 then PI=8;
if 30 ≤ RIF≤ 39 then PI=7;
if 40 ≤ RIF≤ 49 then PI=6;
if 50 ≤ RIF≤ 59 then PI=5;
if 60 ≤ RIF≤ 69 then PI=4;
if 70 ≤ RIF≤ 79 then PI=3;
if 80 ≤ RIF≤ 89 then PI=2;
and, if 90 ≤ RIF≤ 100 then PI=1

Subsequently, Table 4 shows the Relative Importance Factor (RIF) and the Priority Index (PI) of several construction errors in Tehran.

Table 4. Relative Importance Factor (RIF) and Priority Index (PI) of construction errors in Tehran

Relative Importance Factor (RIF)	Type of problem	Priority Index (PI)
100	Lack of sampling or wrong sampling	1
100	Use of untrained workers	1
99	Out of specification aggregates	1
98	Wrong vibration	1
98	Scrimp tests	1
94	Weak curing	1
92	Lack of geotechnical investigation and tests	1
83	Scrimp supervision	2
75	Lack of mix design	3
74	Wrong concrete casting	3
	NO CASE	4
56	Weak façade structural details	5
56	Inattention to HSE concepts	5
49	Wrong discontinuity joints	6
38	Wrong stair and lift details	7
38	Scrimp welding slag removing	7
34	Weak welding	7
34	Overloading	7
31	Use of slender walls	7
30	Wrong dimensions of elements	8
28	Unsuitable storage of materials	8
26	Wrong construction joints	8
23	Steel bars displacement and deformation	8
22	Scrimp assembled joints	8
22	Twisted or nonalignment members	8
19	Use of second-hand materials	9
18	Wrong demolition of concrete	9
18	Off-axis foundations	9
16	Waste filled concrete	9
16	Weak foundation	9
16	Weak base plate	9
15	Weak reinforcement steel hooks	9
15	Stiffness and slenderness changing	9
14	Use of stained steel	9
13	Unauthorized changes of drawings	9
9	Undefined / wrong connections	10
9	Wrong construction wastes management	10
7	Use of nonstandard materials	10
7	Painted steel welding	10
6	Casting in unconventional weather	10
5	Use of dirty materials	10
3	Weak shotcrete	10
3	Multi-parted bracing	10
3	Incomplete connections	10
2	Un-provided cover	10
2	Inadequate tension of bolts	10
1	Use of unsuitable water	10
1	Unsuitable welding electrode	10
1	Weak connection to tubular members	10
1	Unsuitable welding polarization	10

The geographical distribution of construction errors is shown in Fig. 12.

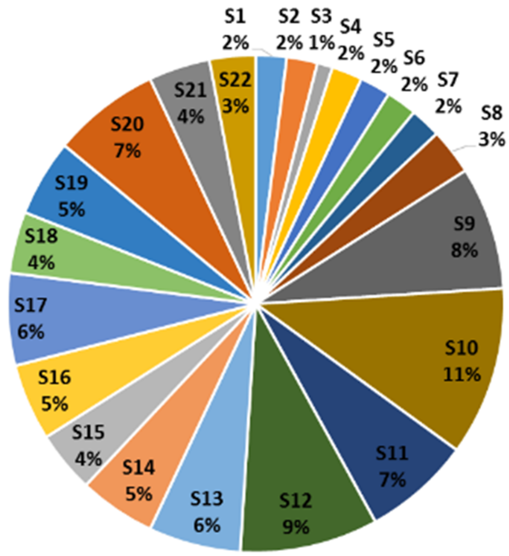

Fig. 12. The distribution of construction errors in Tehran suburbs

4. Conclusions

Based on the results of the study the following most important conclusions are drawn:

- "Lack of sampling or wrong sampling" and "use of untrained workers" are visible in almost all construction sites in Tehran.
- 99% of building projects in Tehran use "out of specification aggregates".
- The probability of at least one of the two errors, "wrong vibration" or "scrimp tests" in Tehran's building projects is 98%.
- More than 93% of concrete structures are not well-cured in Tehran.
- In 92% of construction projects, reliable geotechnical tests are not carried out.
- Only 17% of the buildings are under proper supervision. Therefore, in 13% of projects, unauthorized changes to drawings have been observed.
- Less than 25% of structural concrete have a proper mix design and are cast in the correct way.
- 56% of façades of Tehran's buildings have a weak structural system.
- In 56% of cases, no attention is paid to the HSE concept.
- 49% of discontinuous joints and 26% of construction joints are not properly built. Also, 22% of structural joints are assembled with obvious faults.
- Stairs and lifts do not have the correct structural detail in 38% of buildings.
- 34% of welding connections are weak. Also, in 38% of cases, the slags have remained on the weld.
- 34% of buildings are exposed to loads not considered in the design.
- The slenderness of 31% of walls is beyond the standard limits.
- The design dimensions of structural elements are not met in 30% of buildings.
- The Relative Importance Factor and Priority Index of each "Lack of sampling or wrong sampling" and "use of untrained workers" are 100 and 1 respectively.
- Suburb 3 (S3) has the best construction condition but, suburb 10 (S10) has the worst one.
- By identifying the common factors of the structural weakness of buildings and by teaching the results of this research to students and engineers, a significant improvement in engineering education would happen. Also, by introducing the architectural mistakes which can affect the safety of buildings in the construction phase, the technical view of architects could be enhanced. The mentioned points can be used to enhance construction codes and buildings inspection policies through adding new technical notes. Also, the results of this research can be used to raise the technical understanding of the community regarding the importance of the construction phase. This can reduce unnecessary savings that lead to the loss of quality of buildings.

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