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# TIME AND COST IMPACTS OF REWORK IN BUILDING CONSTRUCTION PROJECTS

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***Abstract— In construction industry, rework is one of the major factors that affect the success of a construction project. It causes to decrease the quality and productivity, and increases the cost and time of construction. Rework commonly happens due to insufficient supervision, poor workmanship, wrong or defective materials, etc.***

***This research intends to determine the cost of waste and time delay due to reworks in the construction of reinforced concrete structure, to investigate the factors affecting the rework such as contractors, owners, and consultants. Also in this research the rework items, their frequencies, their correlation, and their impact on cost of waste and time delay were investigated. A case study project consisted of three 8-storeys buildings was observed and studied, and a questionnaire survey was undertaken among 22 construction projects to collect data. The case study and questionnaire survey findings revealed that, the reworks influenced the cost by 1.85% and 2.1% of construction cost respectively. Also the findings indicated that, the time delay of rework in case study and survey was 4.1% and 5.18% of construction duration respectively. It was obtained that, the major rework items affecting the cost were: 1- allocating inappropriate concrete materials, 2- changing the designed steel bar diameters due to unavailability, and 3- forming cold joint due to mismanagement of concrete delivering to the site. The major rework items that affecting the delay were: 1- collapsing excavation walls, 2- over excavation, and 3- falling formwork materials from top storeys that causes damage to them.***

***Keywords: rework, cost, time, rework factors, reinforced concrete structure***

## 1.1 Introduction

The importance of construction industry is approved in all communities. It is one of the major industries in the economic growth and civilization. A huge amount of money, time and energy consuming in this part indicate the important role of this industry. Construction industry not only includes buildings construction, but also covers roads, bridges, dams and skyscrapers construction. Construction methods have been changed enormously since human started to construct shelters. There was not adequate design information and people had to do everything by human force because there was no machine at that time. The methods of construction improved through thousands of years and new construction technologies emerged meanwhile. As technologies are improved nowadays, construction industry is getting automated and prefabrication method becomes very popular in many countries. Although the role of human in construction is decreased in recent years, still human has a major role, so mistakes are still exist.

In the process of construction, mistakes frequently occur and they lead to reworks in different stages of construction. In general, reworks and wastages are known as nonvalue adding symptoms that affect the productivity and performance in construction projects (Alwi et al., 2002) and probably the most complete definition of rework is provided by Ashford (1992) which defines rework as the procedure that is making an item to adjust with the original requirements by correction or completion. Rework may happen because of the lack of quality control, insufficient maintenance, using unskilled workers and inadequate tools, etc. The reworks sometimes are happening as demolishing and rebuilding and sometimes as requirement of extra works.

The most important effect of rework is on productivity and productivity influences cost, time, and quality within the construction project. According to Kazaz and Ulubeyli (2007), enhancement of productivity has many advantages such as reducing total cost and production duration, improving quality, increasing product market share, and increasing salaries and employment. Generally, productivity growth is the most important economic indicator through it fast living standard growth could be attained (Tucker, 2003).

During 1980s and 1990s most of the United States economy sectors showed growth in labor productivity, however the construction sector was the only sector which had noticeably decline in its labor productivity as shown in Figure 1.1. Labor productivity is defined as the output per working hour and is one of the best production efficiency indicators (Rojas and Aramvareekul, 2003).

Enshassi et al. (2007) identified 45 factors that negatively affect construction labor productivity. The first three items were: material shortage, lack of labor experience, and lack of labor surveillance. Rework was ranked as 11th most effective factor that affects the productivity of construction labor, negatively.

**1.2 Case Study**

A construction project in Shiraz, Iran, was chosen as a case study project. In my opinion, Shiraz is the center of civil engineering in Iran and it has the most number of civil engineers in compare with the population in this country. It was awarded as the city with the best quality of construction in recent years in Iran, so the construction of this city represents the high quality construction among developing countries.

1.2.1 Project Specifications

The case study project was three blocks of 8-storeys residential buildings including 2 stories of parking and storage, and 6 residential stories. Number of residential units of each floor was 5, so each block comprised of 30 residential units and the total number of units of the project was 90. Each residential floor consisted of 1 one-bedroom unit, 2 two-bedroom units, and 2 three-bedroom units with the area of 73, 100, and 127 square meters of each unit, respectively. The total construction area was 12000 square meters.

The volume of soil excavation of each block was 1700 cubic meters with the excavation area of around 500 square meters (28.5×17 meters) and the excavation height of 3.5 meters. Excavation was done mechanically by using loader for digging and truck to transfer the soil.

According to the results of soil test, constructing the pile under the foundation was needed. 6 circular reinforced concrete piles with a diameter of 1 meter and length of 8 meters with the same concrete specifications of foundation were constructed for each block.

10 centimeters of blinding concrete was placed on the soil. The total volume of cleaning concrete was 45 cubic meters with the cement ratio of 150 kilograms per cubic meter, which was transferred from batching plant to the site.

The type of foundation is mat foundation. 450 cubic meters of concrete were placed to construct the foundation of each block and this was done by discharging 65 truck mixers which transferred the concrete from batching plant of the Fars cement company. The thickness of foundation was 90 centimeters and it was constant for the whole foundation. The weight of reinforcement of each block‘s foundation was 30 tons including two layers of steel bars at the top and bottom, and confirmatory bars. The required strength of foundation concrete was 250 kilogram per square centimeter for the 28 days cylinder sample. One concrete sample test was taken for every 50 cubic meters of concrete. Steel formwork was used and concrete was cured for 8 days by keeping it wet and under normal temperature.

The structure of building was reinforced concrete with shear walls, and two-way slabs for the roofs. Rectangular columns started with dimension of 50×50 centimeters on the basement and they reduced to 40×40 centimeters at the top. Dimension of beams was 40×40 centimeters and it was the same for all floors. The thickness of basement‘s roof was 17 centimeters which was constructed by using two layers of steel bars (mesh), and the roof thickness of other floors were 15 centimeters. 2 ducts were passed through the slabs of top 6 storeys and 12 ducts from second floor to the top. 21 shear walls were constructed for each block of the project including: 5 shear walls with the thickness of 35 to 45 centimeters from the basement to the top, 9 shear walls with the thickness of 30 centimeters just in the underground floor, 5 shear walls with the same thickness just for the first two floors, and the rest 2 shear walls with the thickness of 20 centimeters from the


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second floor to the top. Each shear wall included two layers of steel bars.

Metal formwork was used for the structural concrete works. The concrete volume of the top 6 storeys was 140 cubic meters for each floor and the designed strength of concrete for structure including columns, beams, shear walls, and roofs was 300 kilograms per square centimeter for the 28 day cylinder sample. For every column and shear wall, one concrete test was performed.

### 1.3 Data Analysis and Discussions

Results of the study and their analysis are provided in this chapter with their explanations and discussions. This chapter is divided into four sections, the first section represents the cost of rework in the construction of reinforced concrete structure, the second section covers the time wasting of rework in the stated phase of construction, the third section presents the factors of rework (contractor, owner, consultant) and the influence of each one in the cost of rework, and the final section provides some rework items in different phases of construction, relations between the items of each phase, their frequency, and their effect on cost and time of rework.

#### 1.3.1 Rework Cost

In this section, rework cost is given as a percentage of the construction cost of building a reinforced concrete structure. The average of rework costs of all projects are then calculated as the mean of rework cost.

The result of observations and data collection from case study project showed that the cost of rework was $33,225. This amount was gained by summing up the cost of rework items (the sample of rework items are given in the section 4.5) that happened during the construction. The construction activities that considered in this study were excavation, reinforcing, formwork and concrete work of constructing reinforced concrete structure. The total cost of construction was $1.8M. By dividing the cost of rework to the construction cost, it is found that the rework cost is around 1.85% of the construction cost during the observation period. It means that for the construction of reinforced concrete structure in the case study project, this amount of money is wasted due to rework.

The rework costs of 22 construction projects are shown in the Figure 4.1. This figure shows the frequency of each rework cost among the projects. The horizontal axis represents different rework costs in percentage of construction cost and the vertical axis indicates the frequency of each rework cost among the surveyed projects. The results are according to the data collected by a questionnaire survey from different constructing or constructed projects.

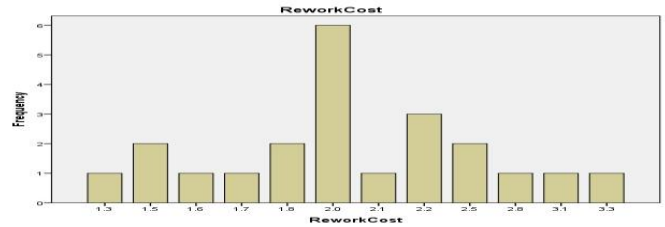


Figure 1.1. Rework costs and frequencies

All analysis and charts of this chapter are done and drawn by Statistical Package for Social Sciences or ―SPSS‖ software version 20.

The rework cost of the case study project is 1.85% and the mean of rework cost gained from 22 projects is 2.095%. By dividing the first number to the second one and multiply it by hundred, it is found that there is an about 12% relative difference between these two and it is reasonable because the projects are different in size, conditions, supervisions and etc.

### 1.4 Rework Time

Rework times are provided as a percentage of the period of constructing reinforced concrete structure in this chapter. The time wastage of rework in the case study project comes first and the rework times of the 22 surveyed projects come after. In the case study project, time delay due to rework was observed as 15 days and the duration of constructing the structure was 365 days so, the rework time in the case study project is 4.1% of the construction period. The mentioned time delay is the wasting time to make the rework items correct. By a questionnaire survey, rework time of 22 construction projects were gathered and it is shown in the Figure 1.2. Different rework times in percent of construction duration are given in the horizontal axis and the frequency of each rework time among 22 surveyed projects are demonstrated in the vertical axis. It indicates the frequency of each rework time among the projects. In the figure, rework time are given as a percentage of construction period.


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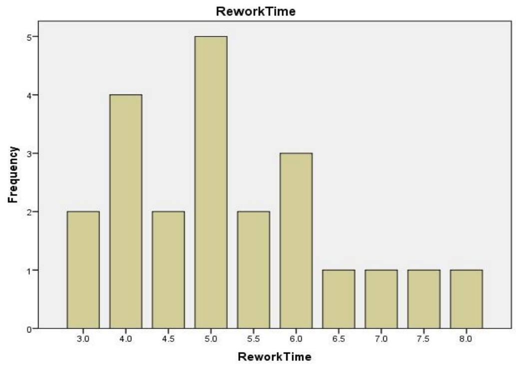


Figure 1.2. Rework times and frequencies

Table 1.1 indicates the rework times and the frequency of each number in both frequency number and percentage. It shows that from 22 projects, rework time of 5% is happened in 5 projects with frequency percent of 22.7%. The second most repeated rework time is 4% which is the same in 4 projects with frequency percent of 18.2%, and the third rank belongs to 6% rework time with 3 times or 13.6% repeating frequency. Rework times of 3%, 4.5%, and 5.5% are occurred 2 times each one.

Table 1.1. Rework time frequencies

| Rework time | Frequency | Percent | Valid Percent | Cumulative % |
|---|---|---|---|---|
| 3.0 | 2 | 9.1 | 9.1 | 9.1 |
| 4.0 | 4 | 18.2 | 18.2 | 27.3 |
| 4.5 | 2 | 9.1 | 9.1 | 36.4 |
| 5.0 | 5 | 22.7 | 22.7 | 59.1 |
| 5.5 | 2 | 9.1 | 9.1 | 68.2 |
| 6.0 | 3 | 13.6 | 13.6 | 81.8 |
| 6.5 | 1 | 4.5 | 4.5 | 86.4 |
| 7.0 | 1 | 4.5 | 4.5 | 90.9 |
| 7.5 | 1 | 4.5 | 4.5 | 95.5 |
| 8.0 | 1 | 4.5 | 4.5 | 100.0 |
| Total | 22 | 100.0 | 100.0 | |

Table 1.2 illustrates that according to the data collected from 22 construction projects, the minimum rework time of constructing a reinforced concrete structure is 3% of the construction period and the maximum number is 8%. The average of rework times is 5.182%. In compare to the rework time of case study project, which is 4.1%, the rework time of the surveyed projects is 1.082% more than case study project which shows about 21% relative difference.

**Table 1.2. Rework time descriptive statistics**

| Descriptive stat. | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| ReworkTime | 22 | 3.0 | 8.0 | 5.182 | 1.3233 |
| Valid N (listwise) | 22 | | | | |

### 1.5 Rework Factors

Rework factors that investigated in this study are: contractor, owner, and consultant. The role of factors is shown as the percentage of rework cost happened because of each one‘s mistakes.

### 1.5.1 Contractor

In the case study project, contractors were the most responsible factor in the costs of rework and it made 46% of rework costs. The results of survey are given in the Figure 1.3. In this figure, horizontal axis shows different percentages of the share of contractor in the rework cost and vertical axis indicates the frequency of each number among 22 surveyed projects.

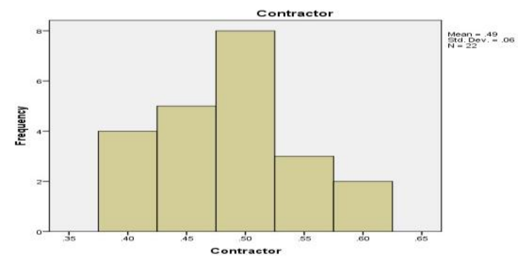


Figure 1.3. Contractor's share in rework cost

Table 1.3 indicates the percentage of contractor‘s share in the cost of rework and the frequencies of repeating that percent among 22 projects. It shows that 50% share of contractor in rework cost is the most frequent, which happened in 8 projects.

**Table 1.3. Frequencies of contractor‘s share in rework cost**

| Contractor's share | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|
| .40 | 4 | 18.2 | 18.2 | 18.2 |
| .45 | 5 | 22.7 | 22.7 | 40.9 |
| .50 | 8 | 36.4 | 36.4 | 77.3 |
| .55 | 3 | 13.6 | 13.6 | 90.9 |
| .60 | 2 | 9.1 | 9.1 | 100.0 |
| Total | 22 | 100.0 | 100.0 | |

According to Table 1.4, the minimum influence of contractor in rework cost is 40% and the maximum is 60%. In average 48.64% of rework cost belongs to the contractor.

**Table 1.4. Descriptive statistics of contractor‘s share in rework cost**

| Descriptive stat. | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Contractor | 22 | .40 | .60 | .4864 | .06012 |
| Valid N (listwise) | 22 | | | | |



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### 1.5.2 Owner

The share of owner in the cost of rework in the case study project was 37% of the rework cost, indicates that owner is the second most important factor in the rework cost after contractor.

According to the survey of 22 construction projects, the owner's shares in the rework cost are shown in the Figure 1.4. In this figure, horizontal axis represents various percentages of the share of owner in rework cost and the vertical axis determines the frequency.

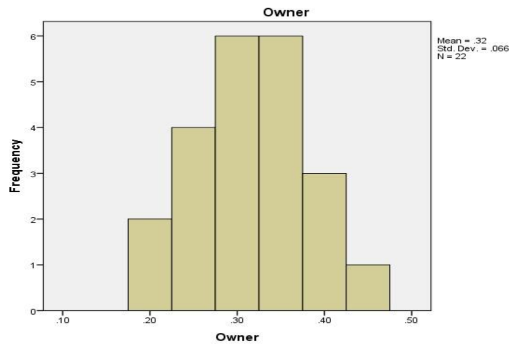


Figure 1.4. Owner's share in rework cost

The owner‘s share percentages in the rework cost and their frequency gathered from surveyed projects are demonstrated in Table 1.5. Referring to this table, 30% and 35% share of owner in rework cost are the most frequent and each one is repeated in 6 projects.

**Table 1.5. Frequencies of owner‘s share in rework cost**

| Owner's share | Frequency | Percent | Valid Percent | Cumulative % |
|---|---|---|---|---|
| .20 | 2 | 9.1 | 9.1 | 9.1 |
| .25 | 4 | 18.2 | 18.2 | 27.3 |
| .30 | 6 | 27.3 | 27.3 | 54.5 |
| .35 | 6 | 27.3 | 27.3 | 81.8 |
| .40 | 3 | 13.6 | 13.6 | 95.5 |
| .45 | 1 | 4.5 | 4.5 | 100.0 |
| Total | 22 | 100.0 | 100.0 | |

Table 1.6 illustrates that 20% is the minimum share of owner in rework cost, 45% is the maximum, and the mean is 31.59% among data collected from 22 projects. Table

**1.6. Descriptive statistics of owner‘s share in rework cost**

| Descriptive stat. | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Owner | 22 | .20 | .45 | .3159 | .06616 |
| Valid N (listwise) | 22 | | | | |

### 1.5.3 Consultant

**The share of consultant in cost of rework in the case study project was observed as** 17%. The results of survey from 22 constructions projects are given in Figure 1.5. Horizontal axis in this chart indicates different percentages of shares of consultant in rework cost and vertical axis shows the frequency among surveyed projects.

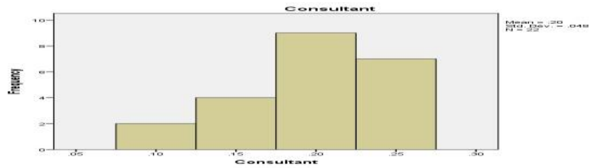


**Figure 1.5. Consultant's share in rework cost**

Table 1.7 demonstrates the consultant‘s share in rework cost and frequency of repeating in surveyed projects. It indicates that in 9 projects out of 22 projects, the share of consultant in rework cost is 0.2 or 20%.

**Table 1.7. Frequencies of consultant‘s share in rework cost**

| Consultant's share | Frequency | Percent | Valid Percent | Cumulative % |
|---|---|---|---|---|
| .10 | 2 | 9.1 | 9.1 | 9.1 |
| .15 | 4 | 18.2 | 18.2 | 27.3 |
| .20 | 9 | 40.9 | 40.9 | 68.2 |
| .25 | 7 | 31.8 | 31.8 | 100.0 |
| Total | 22 | 100.0 | 100.0 | |

According to the Table 1.10, the minimum share of consultant in rework cost is 10% and the maximum is 25%. The mean of data is 19.77%.

**Table 1.8. Descriptive statistics of consultant‘s share in rework cost**

| Descriptive stat. | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Consultant | 22 | .10 | .25 | .1977 | .04750 |
| Valid N (listwise) | 22 | | | | |

Based on the mentioned data analysis, a chart of factor‘s share in rework cost can be drawn. Share of three factors (contractor, owner, and consultant) in the cost of rework in the case study project is provided as a pie chart in Figure 4.6. It shows that 46% of the rework cost are caused by the contractors, 37% by the owner (or owners in this case), and 17% by the consultant.

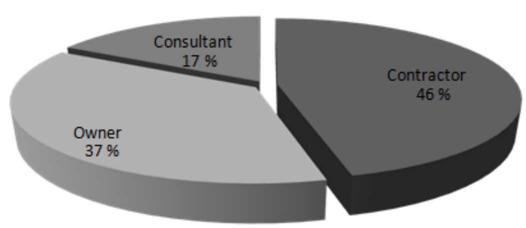


Figure 1.6. Factor‘s share in rework cost in the case study project


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Figure 1.7 shows the average of factor‘s share in rework cost in 22 surveyed

construction projects as a pie chart. According to this figure, share of contractors in rework cost is almost 49%, it is more than 31% for owners, and around 20% for consultants.

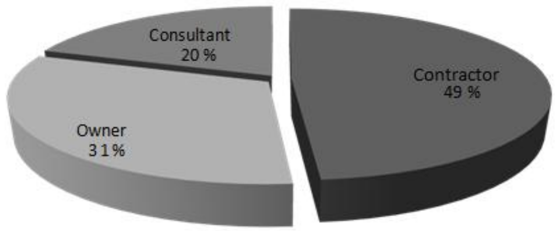


Figure 1.7. Factor‘s share in rework cost in surveyed projects

### 1.6 Rework Items

The rework items observed in the case study project and typical items that occur in most of the construction of reinforced concrete structures are investigated in this research. These items are:

- Over excavation.
- Collapsing excavation walls.
- Appearing cracks at the corners of concrete elements.
- Displacement of formwork at the time of placing concrete.
- Falling formwork materials from top storeys that causes damage to them.
- Bad appearance of concrete surface caused by deformation of formworks.
- Fabricating inaccurately dimensioned concrete elements.
- Damaging formwork materials due to irregular shapes with non-standard sized modular panels.
- Leaking concrete from joints of the formwork.
- Changing the designed steel bar diameters due to unavailability.
- Wasting the reinforcement bars by wrong workmanship.
- Remaining reinforcement bars at the end of construction.
- Lacking reinforcement bars.
- Using inappropriate head for poker vibrators.
- Forming cold joint due to mismanagement of concrete delivering to the site.
- Allocating inappropriate concrete materials.
- Demolishing or repairing some parts of concrete due to non-conformance to the specification.

### 1.7 Cost Effect of Rework Items

Effect of each rework item in cost can be demonstrated by importance index (IMP.I.) of that item in cost. Importance index is the result of multiplying frequency index (F.I.) and severity index (S.I.). The method of calculating these indexes was explained in the previous chapter.

In the excavation phase of construction, over excavation affects the cost more than collapsing excavation walls (Table 1.9).

**Table 1.9. Cost effect of excavation rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Over excavation | 0.500 | 0.386 | 0.178 | 1 |
| Collapsing excavation walls | 0.182 | 0.739 | 0.134 | 2 |

Table 1.10 shows the cost effect of rework items in phase of reinforcing. Changing the designed steel bar diameters due to unavailability has the most influence on cost.

**Table 1.10. Cost effect of reinforcing rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Changing the designed steel bar diameters due to unavailability | 0.636 | 0.511 | 0.325 | 1 |
| Remaining reinforcement bars at the end of construction | 0.455 | 0.466 | 0.212 | 2 |
| Lacking reinforcement bars | 0.545 | 0.307 | 0.167 | 3 |
| Wasting the reinforcement bars by wrong workmanship | 0.273 | 0.488 | 0.133 | 4 |

The cost influence of rework items in formwork phase of constructing a reinforced concrete structure is given in Table 1.11.

**Table 1.11. Cost effect of formwork rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Leaking concrete from joints of the formwork | 0.500 | 0.329 | 0.165 | 1 |
| Damaging formwork materials due to irregular shapes with non-standard sized modular panels | 0.455 | 0.318 | 0.145 | 2 |
| Bad appearance of concrete surface caused by deformation of formwork | 0.318 | 0.295 | 0.094 | 3 |
| Falling formwork materials from top storeys that causes damage to them | 0.273 | 0.341 | 0.093 | 4 |
| Fabricating inaccurately dimensioned concrete elements | 0.318 | 0.261 | 0.083 | 5 |
| Displacement of formwork at the time of placing concrete | 0.409 | 0.193 | 0.079 | 6 |
| Appearing cracks at the corners of concrete elements | 0.273 | 0.215 | 0.059 | 7 |

Finally, Table 1.12 gives the cost influence of rework items in phase of concrete work.

**Table 1.12. Cost effect of concrete-work rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Allocating inappropriate concrete materials | 0.545 | 0.614 | 0.335 | 1 |
| Forming cold joint due to mismanagement of concrete delivering to the site | 0.500 | 0.443 | 0.221 | 2 |
| Using inappropriate head for poker vibrators | 0.591 | 0.239 | 0.141 | 3 |
| Demolishing or repairing some parts of concrete due to non-conformance to the specification | 0.136 | 0.705 | 0.096 | 4 |

Table 1.13 presents the influence of rework items on cost in constructing a reinforced concrete structure.


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**Table 1.13. Cost effect of rework items in constructing a reinforced concrete structure**

| Item | Frequency Index (FI) | Severity Index (SI) | Importance index FI × SI | Rank |
|---|---|---|---|---|
| Allocating inappropriate concrete materials | 0.545 | 0.614 | 0.335 | 1 |
| Changing the designed steel bar diameters due to unavailability | 0.636 | 0.511 | 0.325 | 2 |
| Forming cold joint due to mismanagement of concrete delivering to the site | 0.500 | 0.443 | 0.221 | 3 |
| Remaining reinforcement bars at the end of construction | 0.455 | 0.466 | 0.212 | 4 |
| Over excavation | 0.500 | 0.386 | 0.178 | 5 |
| Lacking reinforcement bars | 0.545 | 0.307 | 0.167 | 6 |
| Leaking concrete from joints of the formwork | 0.500 | 0.329 | 0.165 | 7 |
| Damaging formwork materials due to irregular shapes with nonstandard sized modular panels | 0.455 | 0.318 | 0.145 | 8 |
| Using inappropriate head for poker vibrators | 0.591 | 0.239 | 0.141 | 9 |
| Collapsing excavation walls | 0.182 | 0.739 | 0.134 | 10 |
| Wasting the reinforcement bars by wrong workmanship | 0.273 | 0.488 | 0.133 | 11 |
| Demolishing or repairing some parts of concrete due to nonconformance to the specification | 0.136 | 0.705 | 0.096 | 12 |
| Bad appearance of concrete surface caused by deformation of formwork | 0.318 | 0.295 | 0.094 | 13 |
| Falling formwork materials from top storeys that causes damage to them | 0.273 | 0.341 | 0.093 | 14 |
| Fabricating inaccurately dimensioned concrete elements | 0.318 | 0.261 | 0.083 | 15 |
| Displacement of formwork at the time of placing concrete | 0.409 | 0.193 | 0.079 | 16 |
| Appearing cracks at the corners of concrete elements | 0.273 | 0.215 | 0.059 | 17 |

### 1.8 Time Effect of Rework Items

The influence of rework items on time delay is investigated and it is presented as importance index (IMP.I.) of rework items in this section. Otherwise the cost effect of excavation rework items, collapsing excavation walls has more influence on time delay than over excavation in this phase of construction (Table 1.14).

**Table 1.14. Time effect of excavation rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Collapsing excavation walls | 0.636 | 0.727 | 0.462 | 1 |
| Over excavation | 0.545 | 0.784 | 0.427 | 2 |

Lacking reinforcement bars has the most effect on time delay in phase of reinforcing. Remaining reinforcement bars at the end of construction is the least important item in time delay among reinforcing rework items which has a negligible effect on time delay due to rework (Table 1.15).

**Table 1.15. Time effect of reinforcing rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Lacking reinforcement bars | 0.318 | 0.216 | 0.069 | 1 |
| Wasting the reinforcement bars by wrong workmanship | 0.273 | 0.204 | 0.056 | 2 |
| Changing the designed steel bar diameters due to unavailability | 0.182 | 0.170 | 0.031 | 3 |
| Remaining reinforcement bars at the end of construction | 0.136 | 0.034 | 0.005 | 4 |

The effect of formwork rework items on time delay is provided in Table 1.16.

**Table 1.16. Time effect of formwork rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Falling formwork materials from top storeys that causes damage to them | 0.500 | 0.489 | 0.245 | 1 |
| Fabricating inaccurately dimensioned concrete elements | 0.500 | 0.477 | 0.239 | 2 |
| Damaging formwork materials due to irregular shapes with non-standard sized modular panels | 0.455 | 0.454 | 0.207 | 3 |
| Appearing cracks at the corners of concrete elements | 0.500 | 0.284 | 0.142 | 4 |
| Bad appearance of concrete surface caused by deformation of formwork | 0.545 | 0.227 | 0.124 | 5 |
| Displacement of formwork at the time of placing concrete | 0.455 | 0.182 | 0.083 | 6 |
| Leaking concrete from joints of the formwork | 0.591 | 0.114 | 0.067 | 7 |

Table 1.17 shows the effect of concrete work rework items on time delay.

**Table 1.17. Time effect of concrete-work rework items**

| Item | F.I. | S.I. | IMP.I. | Rank |
|---|---|---|---|---|
| Demolishing or repairing some parts of concrete due to non-conformance to the specification | 0.273 | 0.795 | 0.217 | 1 |
| Allocating inappropriate concrete materials | 0.409 | 0.182 | 0.074 | 2 |
| Forming cold joint due to mismanagement of concrete delivering to the site | 0.318 | 0.193 | 0.061 | 3 |
| Using inappropriate head for poker vibrators | 0.273 | 0.136 | 0.037 | 4 |

**Table 1.18. Time effect of rework items in constructing a reinforced concrete structure**

| Item | Frequency Index (FI) | Severity Index (SI) | Importance index FI × SI | Rank |
|---|---|---|---|---|
| Collapsing excavation walls | 0.636 | 0.727 | 0.462 | 1 |
| Over excavation | 0.545 | 0.784 | 0.427 | 2 |
| Falling formwork materials from top storeys that causes damage to them | 0.500 | 0.489 | 0.245 | 3 |
| Fabricating inaccurately dimensioned concrete elements | 0.500 | 0.477 | 0.239 | 4 |
| Demolishing or repairing some parts of concrete due to nonconformance to the specification | 0.273 | 0.795 | 0.217 | 5 |
| Damaging formwork materials due to irregular shapes with nonstandard sized modular panels | 0.455 | 0.454 | 0.207 | 6 |
| Appearing cracks at the corners of concrete elements | 0.500 | 0.284 | 0.142 | 7 |
| Bad appearance of concrete surface caused by deformation of formwork | 0.545 | 0.227 | 0.124 | 8 |
| Displacement of formwork at the time of placing concrete | 0.455 | 0.182 | 0.083 | 9 |
| Allocating inappropriate concrete materials | 0.409 | 0.182 | 0.074 | 10 |
| Lacking reinforcement bars | 0.318 | 0.216 | 0.069 | 11 |
| Leaking concrete from joints of the formwork | 0.591 | 0.114 | 0.067 | 12 |
| Forming cold joint due to mismanagement of concrete delivering to the site | 0.318 | 0.193 | 0.061 | 13 |
| Wasting the reinforcement bars by wrong workmanship | 0.273 | 0.204 | 0.056 | 14 |
| Using inappropriate head for poker vibrators | 0.273 | 0.136 | 0.037 | 15 |
| Changing the designed steel bar diameters due to unavailability | 0.182 | 0.170 | 0.031 | 16 |
| Remaining reinforcement bars at the end of construction | 0.136 | 0.034 | 0.005 | 17 |

### 1.9 Conclusion

Rework is one of the major determinants of construction productivity. This thesis aimed at investigating the reworks in constructing reinforced concrete structure by determining the wasting cost and time delay due to rework, identifying rework factors, and exploring the frequency and effect of rework items in project cost and time.



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The methodology used in this study was case study and questionnaire survey. The case study project was three blocks of 8-storeys residential buildings with reinforced concrete structure and the total construction area of 12000 square meters. Excavation was done by owner and the construction of reinforced concrete structure was done by main contractor. Main contractor hired subcontractors for execution. The data collection was through the personal observation and also interviews of the civil engineer supervisors. In addition to the case study, a questionnaire survey was conducted among medium to large size (ranged between 5000 to 16000 square meters of construction area) reinforced concrete construction projects. 22 construction projects contributed to this survey.

The results of case study project showed that the cost of rework is 1.85% of the construction cost and time delay due to rework is 4.1% of the duration of constructing reinforced concrete structure. After analyzing the data, similar results were obtained from the questionnaire survey. Survey results indicated that, around 2.1% of the construction cost and 5.18% of the construction time was wasted due to rework.

In the case study project, the share in rework cost was determined as: 46% of contractor, 37% of owner, and 17% of consultant. The relative results of the questionnaire survey indicated that, contractors had almost 49% of the share of rework cost, owners had around 31%, and the share of consultants in rework cost was almost 20%.

Frequency and cost and time severity of 17 common rework items during the construction of reinforced concrete structure consisted of 4 phases of construction were investigated in the survey. Factor analysis was performed to find the correlation among the rework items of each phase of construction. According to the results of questionnaire survey, changing the designed steel bar diameters due to unavailability, using inappropriate head for poker vibrators, and lacking reinforcement bars were the most three frequent rework items, respectively.

The results of factor analysis demonstrated that, 17 investigated rework items can be categorized into 4 components and each component represents one phase of the constructing reinforced concrete structure. These phases are: formwork which represented 33.11% of variance, reinforcing with 21.58%, concrete work with

13.45%, and excavation with 6.89% of represent of variance.

Cost and time effect of rework items were also investigated in this research. For this purpose, importance index of each rework item was calculated by multiplying frequency index and severity index which explained in the methodology chapter. The rework items of each phase of construction and the total rework items were ranked by their importance in cost and time effect separately. Referring to the results, allocating inappropriate concrete materials, changing the designed steel bar diameters due to unavailability, and forming cold joint due to mismanagement of concrete delivering to the site were the most three effective rework items in cost waste due to rework. Collapsing excavation walls, over excavation, and falling formwork materials from top storeys that causes damage to them were three items with the most influence on time delay due to rework.

The results of this study showed that almost half of rework cost in constructing reinforced concrete structure caused by contractors. Lack of construction experience, hiring contractors just based on the offered price, lack of coordination among contractors or between contractor and management team, and lack of sufficient supervision resulted in high level of contractor's share in cost of rework.

The second most effective factor in cost of rework was owners which caused around one third of wasting cost due to rework. Trying to keep the cost down by hiring an inexperienced contractors and not hiring the construction manager, involving in the construction works directly instead of assign it to the consultant, the various number of the owners in one project and interfering all of them in construction instead of choosing one representative, and changing the building plan or materials were the main reasons.

The least effective factor in rework cost was consultants. Some of the reasons that they caused wasting cost due to rework were: having uncertainties about their missions, having ambiguities in case of contracts, being unfamiliar with laws, lack of commitment to their duties, and poor communication.



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In total, the rework items of excavation phase of construction were the least frequent items among 4 phases, they were in the middle of cost effective items, and they had the most effect on time delay. The formwork phase had the most number of investigated items (7 out of 17) but they ranged as the low important items in cost and medium to high important items in time. The number one of most frequent rework item was from reinforcing phase but totally the rework items of this phase were medium to high frequent and they had a medium influence on cost and low influence on time. Finally, the concrete work's rework items ranged as medium to high important items in cost and medium important in time.

To reduce the frequency of rework and eliminate cost wasting and time delay due to rework the following precautions are recommended:

- Owners should avoid involving in construction works such as holding tender directly. It is recommended to assign them to the consultant or representative who is familiar with technical issues.
- Owners should hire the construction manager to do cost and time

management, organize the contracts, select the suitable construction methods or materials and observe the construction process.

- Having a fulltime supervisor in the project site to prevent the rework or make the wrong implemented works correct on time is recommended.
- Preventing reworks to happen by considering the technical competency of the contractors. Most of the time the best contractor to select is not who offered the lowest price as there are hidden costs such as rework cost with them.
- Owners should avoid of making changes in plan or materials at the time construction.
- Try to make the missions and possibilities of the contractors, consultant, and management team clear by writing proper contracts.
- Designers are recommended to use one number of steel bars instead of using similar numbers.
- Do not utilizing substandard materials in construction.
- Managing the available reinforcement bars and avoid of buying more or less amount of bars than are needed for construction.
- Protecting excavation walls from falling by constructing a proper structure.
- Defining the excavation area clearly before excavation.
- Hiring trained workmanship.
- Managing the concrete resources by defining the required number of trucks based on the capacity of the concrete source.
- Providing concrete from trusted source.

**1.9.1 Recommendations**

It is recommended to do further studies on rework in the following areas:

1. Cost and time impact of rework in construction industry.
2. Investigating rework items and factors in construction.
3. Cost and time impact of rework in constructing different types of structure and make comparison.
4. Direct and indirect costs of rework in construction projects.
5. Effects of procurement method on rework in construction.
6. Influences of quality management systems on rework in construction projects.

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