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Application of Pre-fabricated Concrete Elements (PCE) in Construction Projects in Iran

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Abstract: In recent decades, construction waste has become a serious environmental problem in many large cities around the globe. The construction sector in Tehran/Iran produced 50,000 tonnes of waste each day in 2010. Furthermore the growing young population, changing lifestyles and rising demand for housing increases the construction material consumption, hence generating more waste. Two main materials are used to construct buildings in Iran: steel and concrete. Various studies have exposed that use of PCE significantly decrease in the amount of waste production. This study aims to explore advantages, barriers, and potential improvement activities on PCE in Iran based on interviews and a questionnaire survey. Moreover, the three methods of concrete construction that are used in the Iranian, namely in-situ concrete, ready-mixed concrete and PCE have been examined. A case study in Tehran was used to illustrate the concrete waste generation and financial issues of these three concrete work methods. The results of questionnaires illustrate that the main advantages of applying PCE in Iran areon-site concrete waste reduction; improve environmental performance; and shorten project time. Moreover, the most significant hindrances are higher project costs; lack of legislation and regulations; limited manufacturers; and limited products. The findingsof the case study indicate that use of PCE has the most cost and the least on-site concrete waste than the other two methods. Finally, the most mentioned recommendation for improving use of PCE in Iran were governmental incentives for using PCE; and education and training.

Key words: In-situ Concrete, pre-fabricated concrete, concrete waste, ready mixed concrete, waste minimization, Tehran, Iran.

1. Introduction

In recent decades, construction waste has become a significant environmental problem in many large cities around the globe [1]. Construction and demolition (C&D) waste is considered as one of the major producers of the total waste stream due to its massive amount. It is somehow revealed that the material waste in a great number of construction sites is over the acceptable limits [2]. For instance, in Australia the National Waste Minimization and Recycling Strategy has estimated that each year 14 million tonnes of solid waste is disposed to the landfill [2]. Teo et al. [3] reported that in Canada construction waste is estimated about 30 per cent of solid waste. In the USA, it produces approximately 20 per cent of overall landfill waste volume while it produces more than 50 per cent in the UK. In Hong Kong in 2001, the construction and demolition sector has produced more than 40 per cent of the total waste [4]. The Construction industry in Tehran produced 50,000 tonnes of waste each day in 2010 alone [5]. In Tehran the average construction and demolition waste generation is about 4.64 kg per capita per day based on reports from Tehran Municipality Waste Management [6]. Furthermore in Iran the growing young population, changing lifestyles and rising demand for housing increase the consumption of construction material, hence generating more waste in the future [7]. Therefore, minimisation of construction and demolition waste has become a sensitive topic among experts in the construction sector [8]. In order

to minimize the construction waste, apart from waste quantification, which is the initial requirement for the waste minimisation process [9], cost has also traditionally been one of the major elements in the waste minimisation process [10, 11]. From a financial point of view, although waste generated by construction and demolition is a problem for the clients, it is also a problem for the contractors, which could eventually lead to profit loss or even bankruptcy [12].

Concrete has been proved to be a leading construction material for more than a century. It is estimated that the global production of concrete is at an annual rate of approximately 2.5 tonnes per capita [13]. Concrete also has been one of the main waste materials in construction projects [14]. There are different methods for concrete works and each of these methods has its own weaknesses and strengths in terms of minimising concrete waste or the cost of concrete works. The use of ready-mixed concrete and pre-fabricated concrete elements are known to be the two effective methods for minimising concrete waste as opposed to in-situ concrete construction [9, 15-17]. In-situ concrete is the traditional form of concrete construction, which was the main method used for concrete works until the early part of the 20th century [18].

This paper aims to explore the cost and waste production of applying pre-fabricated concrete elements in addition to other two methods of concrete works that are currently used in the construction industry, namely in-situ concrete, and the use of ready-mixed concrete. Advantages, barriers, and potential improvement activities on per-fabrication's applications are also identified based on interviews and a questionnaire survey. In order to retrieve financial in-depth data, a case study was conducted [19] based on the design and build of a seven story residential building project in north Tehran/Iran.

2. Background on Concrete Waste Management

According to Lu and Yuan [20] current construction and demolition waste management research has mostly focused on the use, demolition, recycling, and disposal of construction materials. Therefore, future research is recommended to be extended in the production and delivery of construction materials such as concrete. As stated above, use of PCE is an effective method for minimising the concrete waste in comparison with the traditional in-situ concrete [9, 15-17, 21, 22].

2.1. Pre-fabricated Concrete Elements

Previous studies illustrate that using PCE instead of in-situ concrete can reduce the construction and demolition waste [9]. There is an estimation, which shows that by using PCE the amount of waste can be reduced by between 20 to 50 per cent rather than waste generated on the similar site using traditional construction methods [21]. Poon et al. [22] claims that the use of PCE has exposed a significant decrease in the amount of waste production by approximately 30 to 40 per cent. Pre-fabricated building components can contribute considerably to "zero waste production" because of the dry construction works on site, flexibility in installation, high adaptability, and there use of the elements [23]. Although PCE and in-situ concrete are conducted with the same process, the manufacturers pre-fabricated elements are produced under more controllable conditions. The following functions are some of the waste reduction reasons of pre-fabricated concrete methods to compare with the equivalent concrete work in-situ [21]:

Prevention of long and continuous concrete making and pouring operations

Significant decrease or even prevention of temporary shuttering

Controlled curing of concrete

Enhanced quality controls at the manufacturers

Any unforeseeable stop during the concrete works because of weather conditions

2.2 Ready Mix Concrete

As it is claimed by the ready mix concrete manufacturers, modern formwork systems and efficient site management minimize ready-mixed concrete wastage, by less than two per cent [24]. There is very little waste associated with ready-mixed concrete as the precise volume required can be delivered [25, 26]. Ready mix concrete is used wildly all over the world for concrete works, for instance there are around 1,200 ready-mix concrete plants in the UK, producing 23.5 million cubic meters of concrete each year [27].

2.3 In-situ Concrete

The method of pouring the liquid concrete material into forms at the building site is called in-situ concrete [28]. This was the main method used for concrete works until the early part of the 20th century [18].

There are studies all over the world in relation to the comparison of PCE and other methods of concrete work. For instance the work of De Silva and Vithana [9] compared the three methods together in Sri Lanka. In the UK, a WRAP case study compared the PCE with In-situ concrete in terms of waste production [23]. However, there is limited information for comparison of the afore-mentioned three methods in Iran due to inadequate use of PCE in Iranian construction industry. As a result, it is hoped that the case study used in this paper may shed some light on use of adequate methods in terms of concrete waste minimisation. The reason to use a case study approach is because case studies demonstrate valuable insights in situations where existing knowledge is limited as recommended by Harris and Ogbonna [29].

3. Methodology

3.1 Questionnaire

A questionnaire survey was conducted in Iran with the participants from top 100 contracting companies and 100 top consultants (quantity surveyors). It started with a comprehensive review of existing studies, which discovered several advantages and barriers of using per-fabricated concrete elementsin construction projects. This led to the development of a questionnaire that included ordinal scale multiple-choice questions. The purpose of these questionnaires was to refine the advantages and barriers of using per-fabricated concrete elements, which were identified through literature review. A total of 150 questionnaires were sent to the potential participants that included consultants, general contractors' project managers, and site superintendents, and 56 completed questionnaires were received at the end of sixth week. Therefore, the active response rate for the survey was 37.3%.

3.2 Case Study in Tehran

In order to explore the cost and waste production of the three methods of concrete works, a case study was conducted in Iran. The nature of this research was exploratory followed by descriptive research.

The data collection methods used in this case study were face-to-face semi-structured interviews accompanied by the collection of hard documentary data, and the audit of cost and waste arising.

The case study used in this paper was the design and build of a 7-story residential building project with the concrete frame structure in North Tehran. Each floor above the basement had the same floor plan and sections, therefore volume of concrete works used at each floor was equal.

Contractor used three methods for casting concrete made elements as follows:

In-situ concrete (making and pouring): for floors 5 & 6;

Ready mix concrete: for floors 3 & 4;

Pre-fabricated concrete elements: for floors 1 & 2.

The total floor space was approximately 21,000 Sqft. Construction of the concrete frame structure took approximately 3 months. Costs of any expenditure have been recorded both by the researcher, and the contractor. The contractor agreed to provide the recorded data for the research. The two sets of data for

each concrete work method were collected and then the average was calculated and used in the study [30]. The contractor was chosen from a list of first-grade construction contractors in Tehran [31]. According to the author's experience, usually in Iran both in-situ concrete and ready mix concrete are used in one project in different stages. However for this study, a company who would use all these three methods in one project was needed. This is because in this research having the same conditions (e.g. same environment, same contractor and personnel, same management and so forth) for all the three methods had been contemplated. Therefore after corresponding with 4 contractors, finally Contractor X consented to use these three methods of concrete works together because firstly: the contractor was also client of the project, and secondly: the contractor was interested in investing in the pre-fabricated concrete industry. Usually, it is essential to ensure that the data providers cannot be traced from the output of the research. Statements ensuring anonymity are helpful as are methods that demonstrate anonymity in the data collection, such as not requiring names and addresses of respondents [19].

3.3 Interviews

Nine semi-structured interviews were conducted in Iran in order to refine the claimedbarriers and improvement suggestions on per-fabrication's applications. Seven participants from the questionnaire survey sample frame in Iran agreed to participate in the interviews, as well as two high-level managers from the Tehran Construction Waste Management Organisation, resulting in nine total interviewees. Participants were asked to propose their potential remedies for improving application of PCE in Iran.

The proposed remedies with repetition of 60% and more have been considered as more effective suggestions.

4. Results and Discussion

4.1 Advantages of Adopting PCE in Iran

Several researchers have identified the advantages of using pre-fabricated concrete elements in different countries [32]. However, five advantages were used for conducting this study: (1) on-site concrete waste reduction; (2) improve environmental performance; (3) shorten project time; (4) integrity of the building; and (5) aesthetic issues. The questionnaire survey results are presented in Table 1 and Fig. 1. According to the results, on-site concrete waste reduction; improve environmental performance; and shorten project time are the most significant advantages of using PCE in Iran.

4.2. Barriers for Applying PCE in Iran

Other than the advantages in adopting PCE, the barriers for using it were also investigated [32]. Eight hindrances in applying PCE in Iran were listed for this survey: (1) higher project costs; (2) lack of legislation and regulations; (3) limited manufacturers in Iran; (4) limited products in Iran; (5) storage difficulties; (6) execution difficulties; (7) transportation difficulties; and (8) large number of landfill sites in Iran at the moment. The results are summarised in Table 2 and Fig. 2.

The results reveal thathigher project costs; lack of legislation and regulations; limited manufacturers in Iran; and limited products in Iran are the main barriers of using PCE in Iran.

Table 1 Advantages of using PCE in Iran.

Advantages	Strongly disagree	Disagree	Neither Dis/agree	Agree	Strongly agree	Mean rating
On-site concrete waste reduction			2 (1.3%)	4 (2.7%)	144 (96%)	4.95
Improve environmental performance				12 (8%)	138 (92%)	4.92
Shorten project time			11 (7.3%)	40 (26.7%)	99 (66%)	4.59
Integrity of the building	4 (2.7%)	11 (7.3%)	75 (50%)	42 (28%)	18 (12%)	3.45
Aesthetic issues	5 (3.3%)	21 (14%)	86 (57.3%)	27 (18%)	11 (7.3%)	3.12

Table 2 Barriers of applying PCE in Iran.

Barriers	Least significant	Fairly significant	Significant	Very significant	Extremely significant	Average value
Higher project costs			4 (2.7%)	4 (2.7%)	142 (94.7%)	4.92
Lack of legislation and regulations			4 (2.7%)	9 (6%)	137 (91.3%)	4.89
Limited manufacturers in Iran			6 (4%)	13 (8.7%)	131 (87.3%)	4.83
Limited products in Iran			6 (4%)	13 (8.7%)	131 (87.3%)	4.83
Storage difficulties	4 (2.7%)	11 (7.3%)	73 (48.7%)	44 (29.3%)	18 (12%)	3.41
Execution difficulties	13 (8.7%)	49 (32.7%)	50 (33.3%)	27 (18%)	11 (7.3%)	2.83
Transportation difficulties	9 (6%)	55 (36.7%)	53 (35.3%)	25 (16.7%)	8 (5.3%)	2.79
Large number of landfill sites	31 (20.7%)	51 (34%)	42 (28%)	15 (10%)	11 (7.3%)	2.49

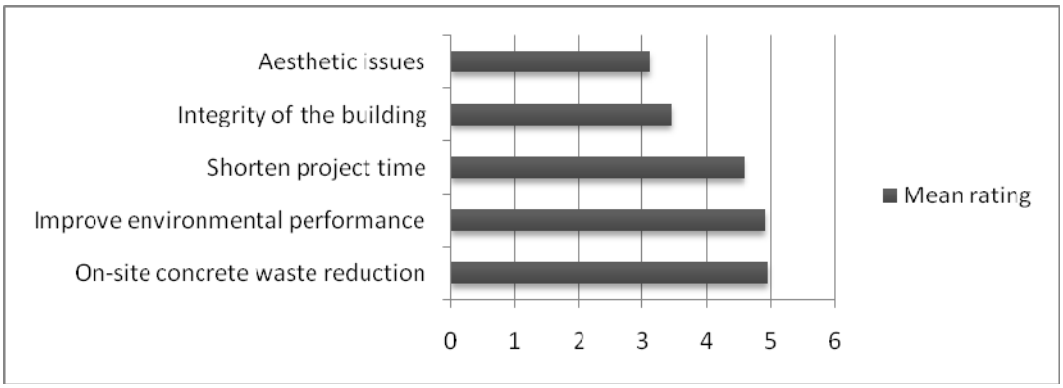

Fig. 1 Agreement levels of stated advantages.

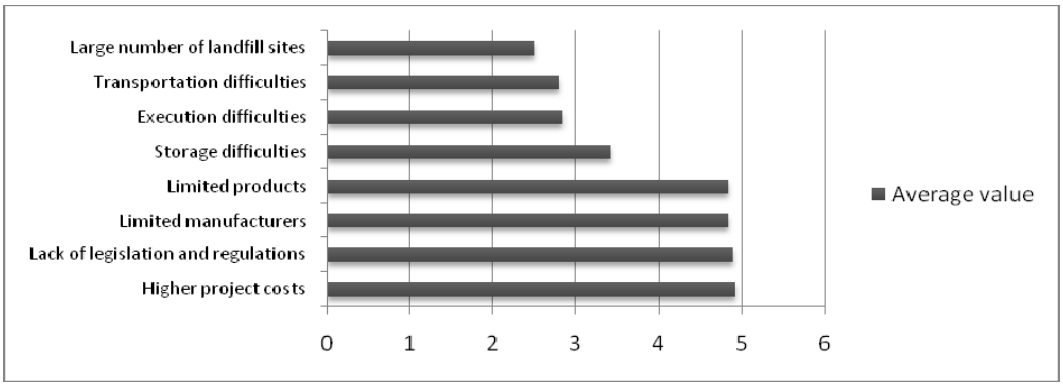

Fig. 2 Barriers of applying PCE in Iran.

4.3. Waste Production and Cost of Applying PCE in Iran

The result of the case study indicates that the use of pre-fabricated concrete elements in this case study has the most cost and least on-site concrete waste in comparison with the other two methods. On the other hand, in-situ concrete (Making concrete on-site) has the least cost, and the most concrete waste production. Two main methods comprising of Interviews and Audits were conducted [33]. Total cost for each method was calculated based on ICBC [34] methods. The results are presented in Table 3, and Figs. 3 and 4.

In order to find out the proportion of each method's expenditure, the percentage of cost for each method is needed. Then percentage of cost of each method in comparison to the total cost of concrete works, have been calculated. Therefore, the percentage of cost of each method by the total cost of concrete works has been achieved. The results are presented in Table 4 below.

Table 3 Cost, and concrete waste generation of methods.

Concrete work method	Total amount of concrete works (m^3)	Cost per cubic meter of concrete	W = Total waste generated (m^3)	W (%)
In-situ concrete (Floors 5 & 6)	470	Equal to £ 72	4.5	0.96
Ready mix concrete (Floors 3 & 4)	470	Equal to £ 103	4.3	0.91
Pre-fabricated elements (Floors 1 & 2)	470	Equal to £170	0.04	0.01

Table 4 Percentage of cost of methods.

Concrete work method	Percentage of cost
In-situ concrete (Average of floor 5 & 6)	20.8 % (PCIN)
Ready mix concrete (Average of floor 3 & 4)	29.9 % (PCRM)
Pre-fabricated elements (Average of floor 1 & 2)	49.3 % (PCP)

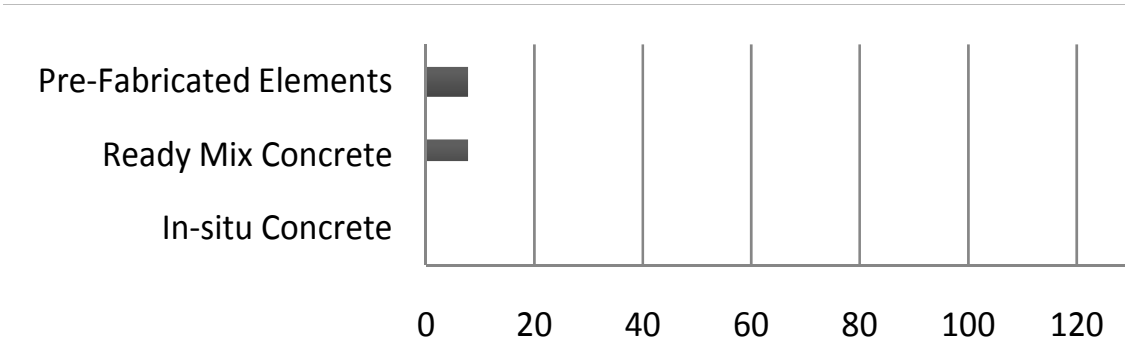

Fig. 3 Total cost of methods per cubic meter.

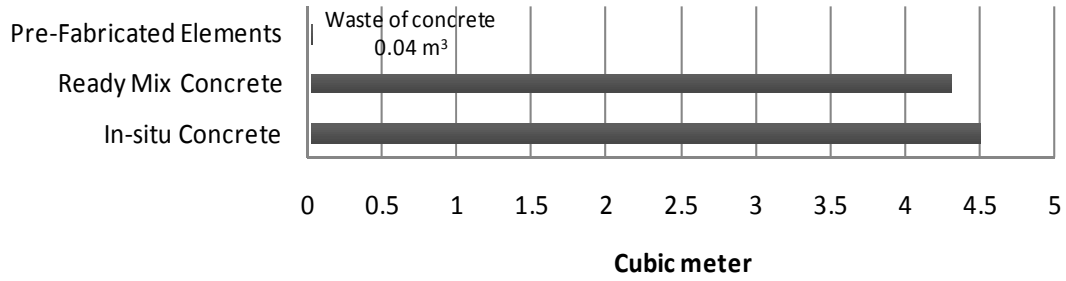

Fig. 4 Concrete waste production of methods.

In order to find out the proportion of the concrete waste generation of each method, waste of each method has been divided by the total amount of concrete waste generated by all three methods. The reason for doing this is the plan volume of concrete works in each floor was equal.

Therefore, the waste generation of each method, have been achieved, Table 5 presents the results, which illustrates the percentage of concrete waste of each method by the total amount of concrete waste for all concrete works.

Finally, in order to illustrate the differences between the methods in a more comprehensible way, the following figures have been drawn, which show the wastes generation (Fig. 5) and the cost (Fig. 6) associated with each method.

However the amount of waste generated from using Ready mix concrete can significantly increase by poor purchase management, the excess ordering of materials, large quantity of concrete remains in pump car and pump pipe and poor quality workmanship at the site level. It therefore appears

that the Iranian contractors would prefer to use either In-situ or ready mix concrete instead of Pre-fabricated Concrete Elements (PCE) due to the high cost of using PCE. The contractor rather pays the tax for the wastes instead of paying nearly double the concrete price in order to reduce the waste by maximum 0.95 percent.

4.4 Recommendations for Improving Use of PCE in Iran

The results of interviews illustrate some recommendation and remedies for improving application of PCE in Iran. Governmental incentives for using PCE; education and training; more demand for using PCE by the clients; more use in designs; more legislation and regulations about waste generation; more investment in PCE; and considering contractors' CSR in biding stage by the clients were the most recommended remedies to increase the application of PCE in Iran. The results are summarised in Table 6.

5. Conclusion

The results of questionnaires illustrate that the main advantages of applying PCE in Iran areon-site concrete waste reduction; improve environmental performance; and shorten project time. Moreover, the most significant hindrances are higher project costs; lack of legislation and regulations; limited manufacturers; and limited products.

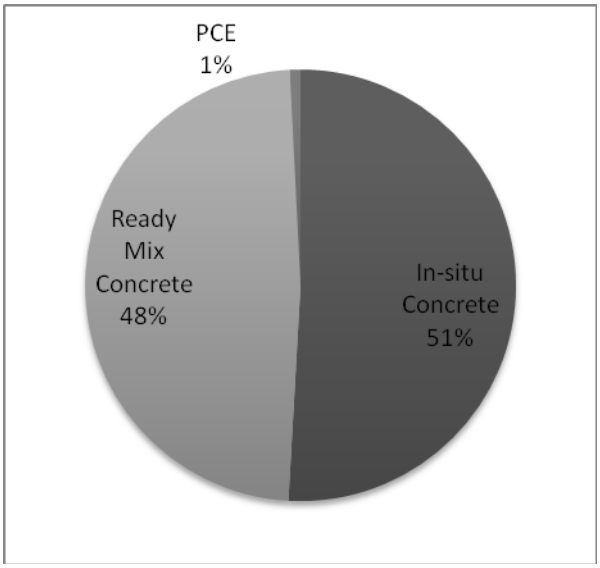

Fig. 5 Percentage of concrete waste generation of methods.

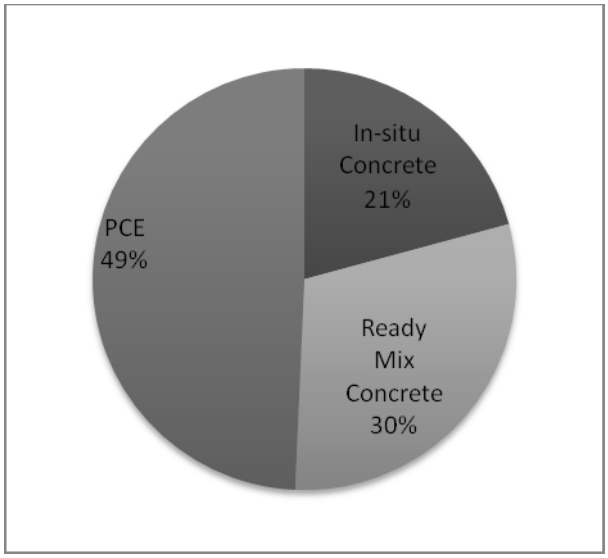

Fig. 6 Percentage of cost of methods.

Table 5 Waste of concrete by volume.

Concrete work method	Total concrete works	Waste of concrete	Percentage of waste in total concrete waste
In-situ concrete (Average of floor 5 & 6)	235 m^3	2.25 m^3	50.9% (PWIN)
Ready mix concrete (Average of floor 3 & 4)	235 m^3	2.15 m^3	48.3% (PWRM)
Pre-fabricated elements (Average of floor 1 & 2)	235 m^3	0.02 m^3	0.8% (PWP)

Table 6 Proposed remedies to improve using of PCE in Iran.

Proposed remedy	Number of repetition
Governmental incentives for using PCE	9 (100%)
Education and training	9 (100%)
More demand for using PCE by the clients	8 (88.9%)
More use in designs	8 (88.9%)
More legislation and regulations about waste generation	8 (88.9%)
More investment in PCE	7 (77.8%)
Considering contractors' CSR in biding stage	6 (66.7%)

The result of the case study indicates that use of pre-fabricated concrete elements has the most cost (£170 per cubic meter of concrete) and the least on-site concrete waste (0.01% waste production) than the other two methods. In-situ concrete has the least cost (£72 per cubic meter of concrete), and the most concrete waste production (0.96% waste production). Furthermore, although there is a significant reduction in material waste when pre-fabricated elements are used, the consultants and contractors are still not interested in the usage of this method in their projects in the Iranian construction industry due to the high costs involved with the pre-fabricated construction.

Some recommendations for implementation are highlighted.Governmental incentives for using PCE; education and training; more demand for using PCE by the clients; more use in designs; more legislation and regulations about waste generation; more investment in PCE; and considering contractors' CSR in biding stage, were the most proposed recommendations.

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