WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.146087

ARCHIVES OF CIVIL ENGINEERING

Vol. LXIX ISSUE 3 2023

pp. 385 – 403

Research paper

Decision-making model using the Analytical Hierarchy Process for the selection of the type of concrete and the method of its maintenance in dry, hot climate conditions

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Abstract: The article presents selected types of phase change materials (PCM) and their properties in terms of applications in construction and concrete technology. The purpose of using PCM is to allow the technological barrier to be exceeded in hot and dry climate conditions, enabling the construction of non-cracking concrete structures. Methodology of the multi-criteria decision-making process with the use of a relatively new decision-making tool in construction – the Analytical Hierarchical Process (AHP) is presented. Theoretical aspects of the method and an example of its practical use for the selection of the best material variant and concrete care method in the dry Syrian climate are presented. The conclusions resulting from the presented article concern two areas, i.e. the advisability of using phase change materials for temperature regulation in the maturing fresh concrete in dry climate conditions and the attractiveness of the AHP method justifying the advisability of choosing the maintenance methods in such conditions.

Keywords: multiple criteria decision making methods, Analytic Hierarchy Process, Phaze Change Materials

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1. Introduction

The concreting in hot and dry climates, low relative air humidity, wind speed and high ambient temperature (above 40°C) cause rapid evaporation of water from the mix, which inhibits the proper course of cement setting and concrete hardening [1]. Concrete and reinforced concrete structures executed under these conditions are prone to the formation of cracks and raptures (scratches) in the initial period of concrete mix maturation [2]. Then, significant temperature and temperature gradients form inside the concrete, resulting on one hand from the influence of atmospheric factors and, on the other, from cement hydration. Therefore, it is necessary to maintain the external and internal care of the concrete mix immediately after its arrangement in the structure, to ensure the continuity of the hydration process and concrete setting, and to avoid scratches and cracks in the concrete element caused by loss of mixing water and increment of the temperature inside the concrete element [3].

A necessary condition for the continuation of the correct mixture maturation process is to maintain relative humidity inside the concrete higher than 80%. Because the essence of maintenance is to keep the concrete saturated with water or as saturated as possible, until the spaces originally filled with water in fresh cement slurry are filled to the desired degree by cement hydration products [1].

If the concrete element is constructed without external barriers, it can freely expand during heating and contract during cooling, without causing stresses [3]. In practice, however, concrete is almost always constrained to some extent by adjacent structures (external constraint) or internally due to the temperature increment in the structural member itself (internal constraint). Massive structures, such as dams, have a tendency for thermal cracking in the initial period of maturation [4]. The surface of the concrete mix will cool faster than its core, causing the temperature to rise between the different layers of the structure/element. Thermal differences between parts of the structure will cause tensile stresses on the concrete surface, if these stresses are higher than the actual tensile strength of the concrete, then concrete cracking occurs [5, 6]. Thermal cracking will depend on material, structural and manufacturing factors [4].

Practical measures to mitigate these effects include actions such as: changes in the formulation of the concrete mix (e.g., the use of metallurgical cement or a lower cement content [7]), modifications to the structure design (such as additional reinforcement, pre-stressing, expansion joints) or component cooling mixes or installation of cooling pipes or replacement of part of the mixing water with crushed ice [8]. In construction practice, there are also many other methods of modifying the properties of concrete [9, 10], but new low-cost curing methods are still being sought.

The latest method is the use of Phase Change Materials with the appropriate phase change temperature. It may be a good solution in reducing the risk of thermal cracking in young concrete laid in dry and hot conditions [11–13], also on roads [14] and generally in construction [15–20].

The article focuses on the selection of alternative care methods in dry, Syrian climate conditions, with the justification of this choice using the AHP method.

2. Analytic Hierarchy Process Method

The Analytic Hierarchy Process (AHP) method was developed by Thomas L. Saaty from the University of Pittsburgh in the 1970s. He is also the co-developer of the Super Decisions software [21, 23, 24]. Already upon introduction by Saaty, the AHP method gained great recognition within decision-making processes. Source literature analysis points to several hundred articles focusing on the application of AHP in various fields, among others, agricultural policy [26], engineering geology [27], road building technology [28], logistics and transport [29], development investment [30] etc. It is also used in many countries, such as the United States, China, Japan, Brazil, Czech Republic or Poland, where it is gaining increasing numbers of followers.

The basis of AHP is the hierarchical decomposition of evaluation criteria. Hierarchy of significance in this method has a pre-determined structure. First, you select the target of the decision-making process, then, you set the evaluation criteria and solution variants. In the case of the method in question, the decision-maker is the one who impacts the entire process – AHP is a method that enabled precise selection of the best solution among many variants.

The Analytic Hierarchy Process (AHP) covers 4 inference stages (Fig. 1).

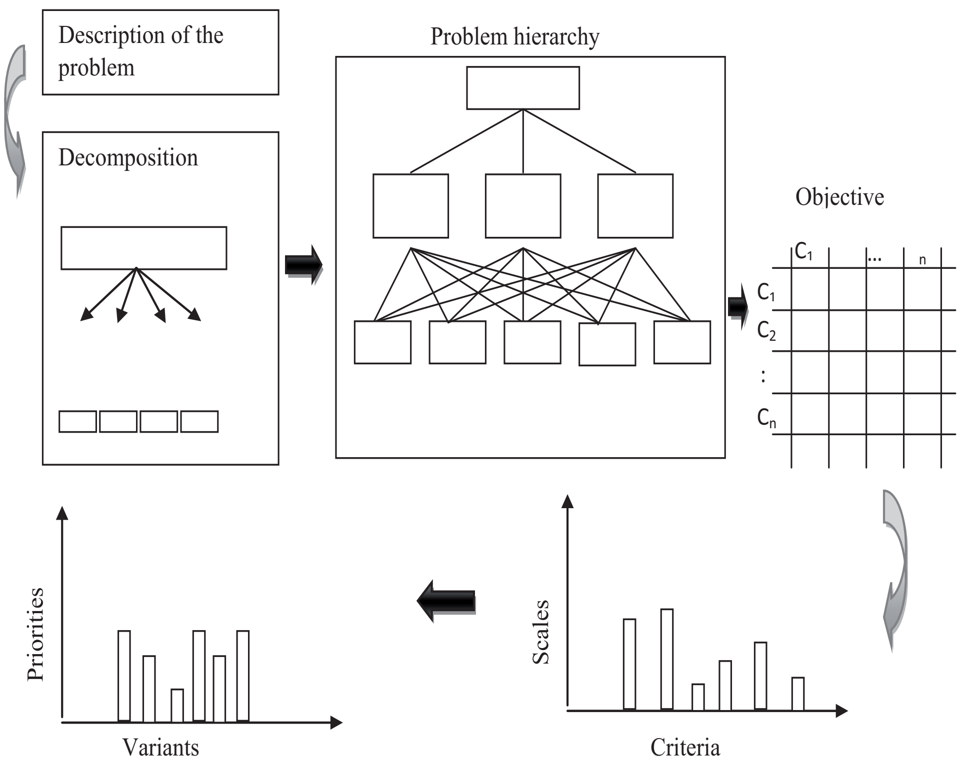

Fig. 1. Structure of Analytic Hierarchy Process AHP [25]

2.1. Problem hierarchization

The objectives of this stage are a detailed description of the problem, identification of components, determination of the primary goal and expectations towards it.

2.2. Criteria assessment through pairwise comparisons

Conducted by the decision-maker who conducts a pairwise comparison with the criteria, and the criteria with the primary objective based on a subjective determination, which of the criteria is more important than the other and to what degree.

The relationships between individual elements are determined based on a 9-point scale [21]:

1 – equal importance;
3 – moderate importance;
5 – strong importance;
7 – very strong importance;
9 – absolute importance;
2, 4, 6, 8 – intermediate values.

This stage ends with the creation of the $\mathbf{A} = [a_{ij}]$ matrix with the dimensions of $n \times n$, where $n(n-1)/2$-th comparisons are made. A characteristic feature of this matrix is its diagonal, which consists of "1" with a property $a_{ji} = 1/a_{ij}$ [31]. This matrix has the following form [31]:

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \tag{2.1}$$

2.3. Determination of mutual preferences (weights) in relation to decision variants and criteria

After creating a matrix within the AHP method using most important quantities that we calculate from the comparison matrix: $\lambda_{\max}$, C.I. and C.R. $\lambda_{\max}$ (greatest matrix eigenvalue) is a measure of comparison consistency that reflects preference proportionality. Saaty demonstrated that pairwise comparisons are the more consistent, the closer $\lambda_{\max}$ is to n (number of elements in a matrix = number of rows = number of columns). In the case of total consistency $\lambda_{\max} = n$.

Adopting this property leads to constructing an inconsistency ratio (lack of comparison consistency) C.I., which represents deviations from consistency. It is calculated from the formula:

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n - 1} \tag{2.2}$$

Another measure measuring pairwise comparison coherence is the C.R. non-consistency index (called the consistency ratio). It is a more useful measure than C.I. (inconsistency ratio), since C.I. is hard to interpret, and C.R. can be expressed as a percentage:

$$\text{C.R.} = \frac{100\,\text{C.I.}}{\text{R.I.}} \tag{2.3}$$

where:

I.R. – inconsistency ratio,

C.I. – consistency index,

R.I. – random index.

This index determines the degree to which mutual comparisons between feature importance is inconsistent (inconsequent) [32]. A practical principle of AHP is that for the C.R. value to be lower than 10% (C.R. $\leq$ 10) [24]. In such a case, it is believed that the inconsistency ratio is acceptable and comparisons are consequent (consistent). Estimating the consistency ratio (C.R.) requires the determination of the R.I., i.e., the random index of inconsistency calculated from a randomly generated matrix with n dimensions. The R.I. (generated from several thousand matrices) in tabular form [24] is presented in Table 1.

Table 1. Value of the RI coefficient [24]

N	0	3	4	5	6	7	8
R.I.	0	0.52	0.89	1.12	1.25	1.40	1.45

2.4. Analysis of selected results

Selection of the best variant that would correspond to the primary objective. This stage is implemented using, among others, "Super Decisions", "Expert Choice" or "AHP Priority Calculator". The latter was used for the calculations and analysis from Section 3.

3. The analysis of the usefulness of the AHP method for the selection of the type of concrete and the method of its maintenance in dry, Syrian climate

The analysis of the proposed technology was conducted using the "AHP Priority Calculator" for selected building structure types, with a large surface modulus $m_p > 10\ \text{m}^{-1}$ such as a drainage ditch, bridge, logistics yard or road surfaces. The consequences of using high, medium and low caloric cements as well as the effectiveness of various methods of curing the concrete mix placed in the structure were considered. In the first decision step four criteria were selected among factors impacting temperature waveform within a concrete mix at the initial curing stage. These are:

– ambient temperature,
– concrete element thickness,
– cement type,
– application of phase-change materials PCM.

In the considered 4 variants, in the first three, the suitability of cement with clearly differentiated heat of hydration "cooled" simultaneously with PCM materials was ranked, in the last one, known concrete curing methods were ranked against the effects of PCM materials.

In the first material variant, CEM III A 42.5 metallurgical cement was used, which is characterized by the lowest heat of hydration compared to the two previously mentioned. The possibility of using PCM materials was also assumed (Table 2, 3).

Table 2. Decision matrix for CEM III A 42,5 cement

No.	1	2	3	4
1	1	0.33	0.20	0.20
2	3.00	1	0.20	0.20
3	5.00	5.00	1	2.00
4	5.00	5.00	0.50	1

Table 3. Priorities – weights of criteria for CEM III A 42,5 cement

No.	Category	Priority	Ranking	plus	minus
1	Ambient temperature	6.30%	4	2.30%	2.30%
2	Element thickness	11.00%	3	4.90%	4.90%
3	Cement	48.30%	1	14.70%	14.70%
4	PCM	34.40%	2	12.60%	12.60%

Number of comparisons = 6; consistency ratio C.R. = 7.9% < 10%. Based on Table 3 – Criteria weight, it can be inferred that cement ranks first in the priority hierarchy in the column ranking, with PCM coming in second place, which is shown in Fig. 2a.

In the second material variant, CEM II A-V 42.5 Portland cement was used. It is a cement with a medium heat of hydration, but its choice for concreting in dry climate conditions is difficult to predict in advance. Hence the analysis was carried out as before (Table 4, 5).

Number of comparisons = 6; consistency ratio C.R. = 2.6% < 10%. Based on Table 5 – criteria weight, it can be inferred that PCM (with priority 41.4%)ranks first in the priority hierarchy in the column ranking, with cement coming in second place, which is shown in Fig. 2b. However, the addition of PCM materials is not as necessary and important as with the CEM I 42.5 N cement.

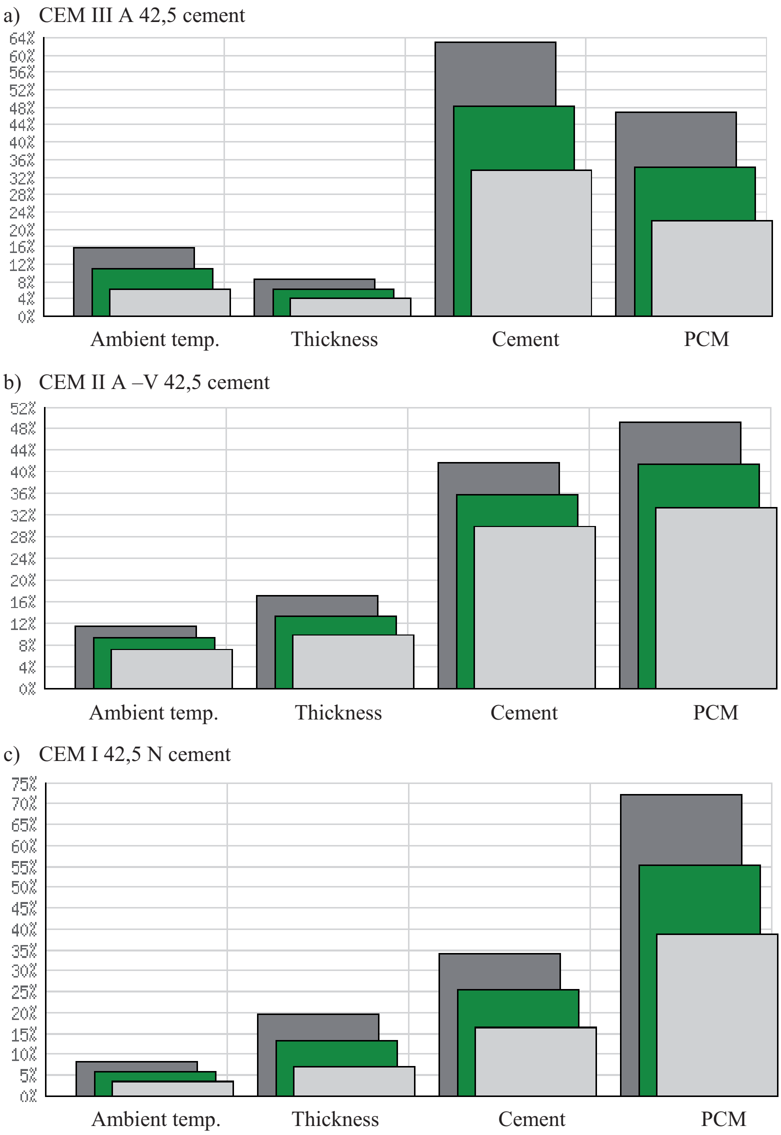

Fig. 2. Comparison of the effect of cement hydration heat against the possibility of cooling concrete mix with PCM materials in dry and hot concreting conditions. The colors in the figure: gray, green, light blue correspond to the maximum, medium and minimum values

In the third material variant of concrete, CEM I 42.5 N Portland cement with a high heat of hydration compared to the previous two was used. It is a cement commonly used in the construction of responsible engineering structures and high durability. However, due to the high hydration heat of this cement (40% higher than CEM II cements and 80% higher

Table 4. Decision matrix for CEM II A-V 42,5 cement

No.	1	2	3	4
1	1	0.50	0.33	0.25
2	2.00	1	0.33	0.25
3	3.00	3.00	1	1.00
4	4.00	4.00	1.00	1

Table 5. Priorities – weights of criteria for CEM II A-V 42,5 cement

No.	Category	Priority	Ranking	plus	minus
1	Ambient temperature	9.4%	4	2.2%	2.2%
2	Element thickness	13.4%	3	3.6%	3.6%
3	Cement	35.8%	2	5.8%	5.8%
4	PCM	41.4%	1	7.9%	7.9%

than CEM III cements), the necessity to cool the concrete by using PCM materials was assumed in advance. The analysis of concreting with such a mixture using a calculator is presented in the Tables 6 and 7.

Table 6. Decision matrix for CEM I 42,5 N cement

No.	1	2	3	4
1	1	0.25	0.25	0.17
2	4.00	1	0.33	0.20
3	4.00	3.00	1	0.33
4	6.00	5.00	3.0	1

Table 7. Priorities – weights of criteria CEM I 42,5 N cement

No.	Category	Priority	Ranking	plus	minus
1	Ambient temperature	5.9%	4	2.3%	2.3%
2	Element thickness	13.4%	3	6.2%	6.2%
3	Cement	25.4%	2	8.8%	8.8%
4	PCM	55.3%	1	16.7%	16.7%

Number of comparisons = 6; consistency ratio C.R. = 8.2% < 10%. It is a rule of thumb for an AHP to ensure that the C.R. was less than 10% – this condition has been met. Based on Table 7 – criteria weight, it can be inferred that PCM ranks first in the priority hierarchy in the column ranking(with priority 55.3%), with cement coming in much lower second place, which is shown in Fig. 2c.

The second decision-making step concerned the selection of care methods for the concrete mix placed in the structure. In the fourth variant, a comparisons was made between four different curing techniques that are most often used in dry and hot climate conditions and the effects of cooling concrete with PCM materials.

These are:
- water sprinkling or spraying,
- water-saturated fabric,
- plastic foil,
- film-forming preparations and PCM.

The analysis regarding the selection of the best curing method among the aforementioned ones was conducted using a calculator AHP. The analysis results are shown in Tables 8 to 11.

Table 8. The adopted hierarchy of criteria for five care methods

No.	Category	Choise	Variables	Ranking
1	Sprinkling or dousing with water	v	Water-saturated fabric	3
2	Sprinkling or dousing with water	v	Plastic film	3
3	Sprinkling or dousing with water	v	Film-forming preparations	2
4	Sprinkling or dousing with water	v	PCM	3
5	Water-saturated fabric	v	Plastic film	3
6	Water-saturated fabric	v	Film-forming preparations	2
7	Water-saturated fabric	v	PCM	3
8	Plastic film	v	Film-forming preparations	2
9	Plastic film	v	PCM	3
10	Film-forming preparations	v	PCM	3

Table 9. Decision matrix for five care methods

No.	1	2	3	4	5
1	1	0.33	0.33	0.50	0.33
2	3.00	1	0.50	2.00	0.33
3	3.00	2.00	1	2.00	0.33
4	2.00	0.50	0.50	1	0.33
5	3.0	3.0	3.0	3.00	1

Number of comparisons = 10; consistency ratio C.R. = 5.0% < 10%. Based on Table 11 – Criteria weight, it can be inferred that PCM ranks first in the priority hierarchy in the column ranking, with plastic foil in second place, which is shown in Fig. 3.

Table 10. Decision matrix solutions for five care methods

Sprinkling or dousing with water	Water-saturated fabric	Plastic film	Film-forming preparations	PCM
1.00	0.333333	0.333333	0.50	0.333333
3.00	1.00	0.50	2.00	0.333333
3.00	2.00	1.00	2.00	0.333333
2.00	0.50	0.50	1.00	0.333333
3.00	3.00	3.00	3.00	1.00
0.077383	0.168929	0.222585	0.115774	0.415328
5.223249	0.049631			

Table 11. Priorities – weights of criteria for five care methods

No.	Category	Priority	Ranking	plus	minus
1	Sprinkling or dousing with water	7.7%	5	3.2%	3.2%
2	Water-saturated fabric	16.9%	3	5.2%	5.2%
3	Plastic film	22.3%	2	6.8%	6.8%
4	Film-forming preparations	11.6%	4	2.6%	2.6%
5	PCM	41.5%	1	15.8%	15.8%

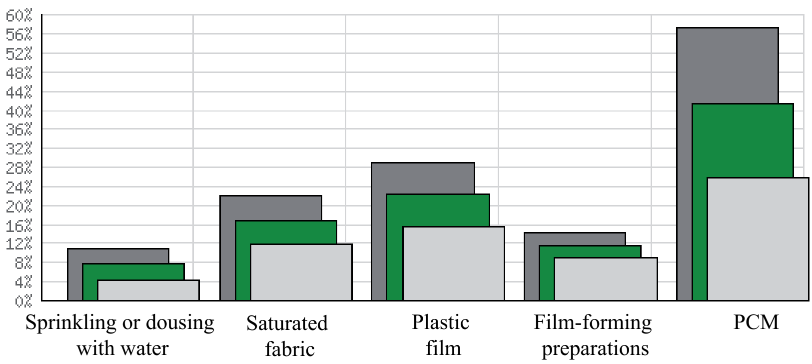

Fig. 3. Cumulative results of comparisons of 5 care technologies. The colors in the figure: gray, green, light blue correspond to the maximum, medium and minimum values

Based on the conducted calculations, it can be observed that the application of PCM is very high in thermal peak reduction hierarchy at the initial stage of concrete mix curing and can be an effective means of cooling the concrete mix at high ambient temperatures with relatively low financial outlays and negligible labor intensity on the part of the construction works contractor.

4. PCM application decision table for concrete curing under Syrian conditions

Curing during a hot period covers all treatments aimed at preventing the formation of excessively large temperature gradients in various parts of curing element – e.g., due to partial shading or uneven exposure to solar radiation or the improper application of a protective material. It is obvious that conducting water curing under hot conditions is more difficult. Higher temperatures intensify water evaporation and facilitate surface drying. This is why, selecting protective measures should take into account both aspects – simultaneous use of a water storage material (e.g., fabric) and a material preventing evaporation (e.g., foil). Dark colours of these materials should be avoided in order to minimize the absorption of solar radiation energy.

The aforementioned issues associated with concreting under high temperature conditions shall be defined as decision-making problems that require solving.

It seems important to distinguish between solving decision-making problems and making decisions. Solving decision-related problems follows seven steps [33]:

1. Problem (and the decision-making objective) identification and definition.
2. Providing possible solutions (variants).
3. Defining criteria impacting the analysis and selection of solutions (variants).
4. Evaluation of individual solutions relative to variants.
5. Best solution selection.
6. Implementation of selected solution.
7. Evaluation of implementation outcomes and verification whether the problem has been solved in a satisfactory manner. The decision itself is only the fifth step, which is the selection of the best solution (Fig. 4).

The source literature contains a proposal of an additional initial stage within the decision-making methodology, namely, observation of a decision-making problem environment. It covers, among others, such activities as site visits, conferences, observations and preliminary testing.

It is a very important stage that enables better identification of the decision-making problem and objective, thus conditioning the effectiveness and credibility of decision results.

Decision tables are means of system documentation and analysis, complementing traditional solution-searching patterns. The basic structural form of decision tables is the condition

$$\gg \text{If } \ldots \text{ then } \ldots \ll$$

making them suitable for use in mathematical processing of information and activities.

Building a decision table for a selected decision-making problem requires to first develop a procedure for selecting the best variant among permissible variants. This involves analysing the criteria and limitations within the selected project. Variants that can be selected shall be subject to evaluation, used as a base to determine their importance hierarchy and applicability conditions. Such an evaluation is best conducted based on

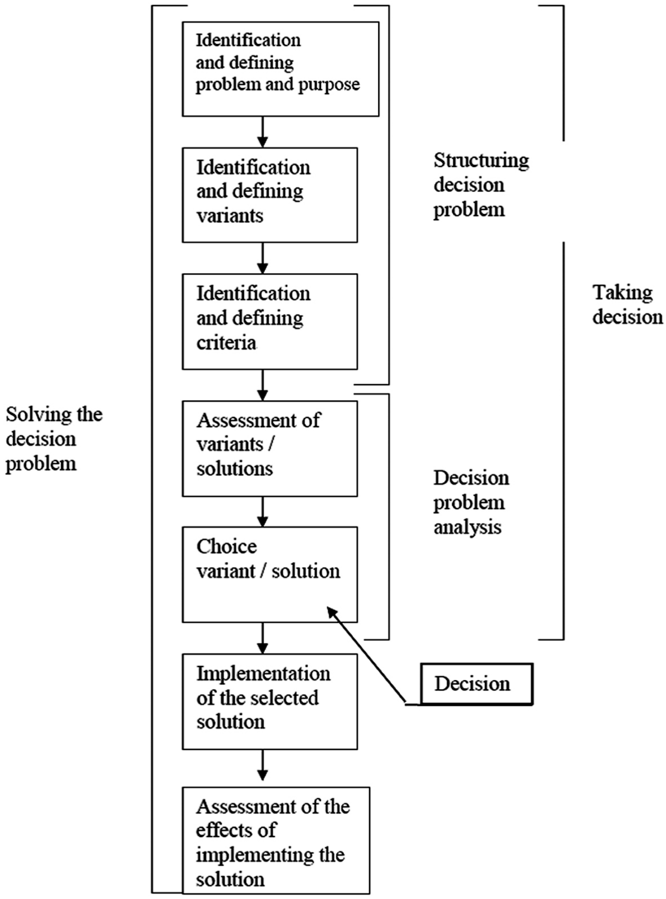

Fig. 4. Solving the decision problem. Source: own elaboration based on [33]

available process knowledge and consultations with experts dealing with technological process engineering [34, 35].

Please bear in mind that concrete structure defects may arise from mistakes made in the course of designing, specifying, supervising, conducting work and selecting materials, especially:
– improper structural design,
– improper design, mixing and thickening of the concrete mix,
– insufficient concrete cover,
– insufficient or defective waterproofing insulation,
– application of poor-quality, reactive or contaminated aggregate,
– improper curing [7, 8].

A decision table that takes into account the new technology described in this paper was created in order to facilitate making the right decision by the personnel supervising concreting in hot climate conditions.

The following division is suggested depending on variable conditions (with focus on air temperature [36]):

– good concreting conditions, i.e., from 15°C to 24.9°C,
– acceptable concreting conditions, i.e., from 25°C to 34.9°C,
– difficult concreting conditions, i.e., from 35°C to 44.9°C,

Every curing method that satisfies the continued hydrated condition (maintaining relative humidity of at least 80% inside the concrete) is permissible. All this because ***the movement of water between water and the surrounding will be minimal*** at such and higher relative air humidity. In such a case, no water curing is required to ensure continued cement hydration, provided that no other factors impact the structure, i.e., there is no wind, no temperature difference between the concrete and air, and the concrete is not exposed to solar radiation. It follows that curing becomes unnecessary only in a very humid climate with a constant temperature. Unfortunately, virtually always relative air humidity is lower than 80% – which is the minimum humidity for the correct course of hydration, especially under conditions described in this paper. This is why curing fresh concrete immediately after pouring in a structure becomes necessary. ITB (Building Research Institute) guidelines [37] on concrete curing condition the curing period length upon cement type. According to these guidelines, concrete should be maintained under constant humidity for at least:

– 7 days – when using Portland cement (CEM I),
– 14 days – when using metallurgical and other cements (CEM II, CEM III, CEM IV).

Depending on the forecasts and weather conditions prevailing at the time of concreting, the tables below present a number of possibilities that enable selecting an adequate curing method for the completed structure.

Simple and inexpensive treatments in order to ensure correct concrete mix curing can be applied in the case of the first temperature range, i.e., under good concreting conditions from 15°C to 24.9°C. It should be emphasized that despite the prevailing good concreting conditions, at least one of the curing treatments in Table 12 shall be conducted.

Table 12. Methods of maintaining the mixture in the range of 15–24.9°C.

1. Good conditions for concreting, ie from 15°C to 24.9°C	
External humidity care	Wet care a) sprinkling or sprinkling with water, b) saturated fabric,
	Maintenance using a coating c) plastic film, d) paper reinforced with a bituminous binder, e) film-forming preparations.

The second of the temperature ranges, 25°C to 34.9°C, induces several more issues related to ensuring correct course of hydration. Table 13 shows curing methods, one of which must be applied under such climate conditions.

Table 13. Methods of maintaining the mixture in the range of 25–34.9°C

2. Acceptable conditions for concreting from 25°C to 34.9°C	
Moisture care outside (Surface impact)	Wet care a) sprinkling, b) pouring water on it, c) fabric saturated with water.
	Maintenance using a coating d) plastic film, e) paper reinforced with bituminous binder, f) film-forming preparations, g) a layer of sand (about 0.1 m thick) on the surface of fresh concrete poured with water to prevent evaporation and the formation of cracks (as long as the concreted surface is horizontal);
(Internal impact) Thermal interaction	a) Phase Change Materials (PCM) to limit the build-up of concrete temperature due to the release of the heat of hydration by absorbing the heat necessary for the phase transformation of the additive, obtaining as a result, reduction of thermal gradients and reduction of thermal stresses arising between the surface of the mixture and its core, b) internal cooling.
Moisture effect	Internal wet care a) light aggregates saturated with LWA water, b) SAP superabsorbent polymers, c) wood-based filler, d) plain aggregate saturated with water, e) water-saturated recycling aggregate.
	Inner seal a) water-soluble retention polymers – regulating the rheological properties of the mixture.

It is insufficient to only prepare an appropriate concrete mix and correctly pour and thicken it to achieve adequate concrete properties within a structure (among others, compressive strength, abrasion resistance, frost-resistance, water-tightness). Curing, especially at the first hardening stages is extremely important. Improper curing or the lack thereof will lead to reduced concrete durability and quality, and thus – the entire structure. In consequence, it is fully justified to apply flexibility in the form of various procedures ensuring greater continuity of construction work, without unnecessary process interruptions, needless crew, equipment and machinery downtime. Applying one curing method or a combination of several variants from Table 14 is suggested for this purpose.

The combination of impacts recommended in sudden and urgent cases – (e.g., breakdown removal), also when the investment project completion on time is at risk or at a very

Table 14. Ways of maintaining the mixture in the range of 35–44.9°C

3. Difficult conditions for concreting from 35°C to 44.9°C.	
(Surface impact) Moisture care outside	Wet care a) sprinkling or sprinkling with water, b) fabric saturated with water
	Maintenance using a coating c) plastic film, d) paper reinforced with bituminous binder, e) film-forming preparations, f) a layer of sand (about 0.1 m thick) on the surface of the fresh concrete and sprinkle it with water to prevent it from evaporating and the formation of cracks (as long as the concreted surface is horizontal);
(Internal impact) Thermal interaction	a) phase change materials in order to limit the b) build-up of concrete temperature due to the release of the heat of hydration by absorbing the heat necessary for the phase change of the additive, resulting in a reduction of thermal gradients and reduction of thermal stresses between the surface of the mixture and its core, c) internal cooling, cooling the components of the mixture, d) cooling the mixing water or adding crushed ice to the mix, e) cooling with liquid nitrogen (LN).
Moisture effect	Internal wet care a) light aggregates saturated with LWA water, b) SAP superabsorbent polymers, c) wood-based filler, d) plain aggregate saturated with water, e) water-saturated recycling aggregate
	Inner seal f) water-soluble retention polymers – regulating the rheological properties of the mixture
(Combination of actions)	a) cooling the components + PCM, b) cooling the ingredients + internal cooling, c) SAP + PCM superabsorbent polymers, d) setting retarding admixtures + PCM.
Combination of actions recommended for use in emergency and urgent cases – (e.g. removal of breakdowns), also when the timely completion of the investment is at risk and when the ambient temperature is very high, i.e. when there is a need to exceed the technological barrier – (the ambient temperature is above the permissible limit for carrying out or continuing the concreting process).	

high ambient temperature, when there is a need to exceed the process limit – (ambient temperature is higher than the permissible limit for conducting or continuing the concreting process).

5. Conclusions

The conclusions arising from this paper apply to two areas:

- purposefulness of using phase-change materials for adjusting temperature in curing fresh concrete in a dry climate,
- attractiveness of the AHP method for choice of material variant and methods of care in these conditions.

Paying attention to the significant influence of the heat of cement hydration on the actual temperature of the concrete mix laid in the structure, it should be emphasized that it is the phase change materials added to the concrete that allow the typical technological barriers to be exceeded in the case of concreting in unfavorable conditions (hot and dry climate).

Phase-change materials used for modifying cement concrete enable exceeding typical process limit when concreting under unfavourable conditions (hot and dry climate). It is justified to apply process flexibility in the form of several curing variants, depending on concreting and hardening conditions, process capacity of the plant and the type of the concrete element. The application of PCM as a cement concrete modifier enables limiting the thermal peak value and unifying temperature within the concreted element, which leads to reducing the associated risk of element scratching or cracking (which might disqualify it). Adding PCM to concrete also limits the temperature variation range in the course of operating a concrete element, which might lead to increased durability and extending the life cycle of such an element. Adding one or two phase-change materials directly to curing concrete postpones the appearance of the thermal peak, which enables constructing a correct concrete structure, resistant to cracks and scratches. Thanks to PCM, the initial (starting) temperature of the concrete mix is 8°C lower than in the element without the addition of PCM, which is conducive to building the correct structure of young concrete. American standards for concreting in countries with hot and dry climates [8] recommend the use of cements with the lowest possible heat of hydration. This aspect was also confirmed in the AHP analyzes carried out by the authors of the publication. However, the design recommendations for the construction of some concrete objects with high service life show that only full clinker cements (type CEM I 42.5 N), high-calorific ones, are allowed. Then, concreting technologies are complicated and expensive, but similar cooling activities can be achieved with phase change materials, which also give beneficial technological effects. These effects are analyzed in detail in the authors' last paper [13].

The vast majority of decision-making problems that have to be solved by the management of an enterprise within the management process is of multi-faceted nature. An additional element hindering the process of making the right economic decisions is the need to evaluate quality factors that are hard to measure in economic terms. Practical experience and the obtained results for contractors enable creating a so-called "library of good practices" to be used in developing a decision table. This, depending on the climate conditions prevailing on a given day, enables making a decision regarding the recipe of mix components, chemical additives, curing method, etc., which will facilitate and shorten execution time, while simultaneously avoiding unnecessary downtime. This leads to completing a facility on time and in accordance with the schedule. In such situations, the problem's hierarchical analysis method is a very valuable testing tool that helps streamlining and objectifying the difficult decision-making process, while the presented example demonstrates potential benefits of introducing the option of a multi-faceted selection in terms of quality assurance when managing production processes within the construction industry. A significant advantage of this solution is the possibility of cyclic learning based on analysed examples, and systematically gathered information may lead to developing an autonomous advisory system supporting a site manager in making operational decisions.

Acknowledgements

This work was supported by the Poznan University of Technology – Polish Academy of Science under Grant No. 0412/SBAD/0023.

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Model decyzyjny z wykorzystaniem analitycznej metody hierarchizacji procesów do doboru betonu zwykłego lub z dodatkiem materiałów zmiennofazowych wraz ze sposobem jego pielęgnacji w suchych, gorących warunkach klimatycznych

Słowa kluczowe: wielokryterialne metody podejmowania decyzji, metoda AHP, materiały zmiennofazowe

Streszczenie:

W artykule przedstawiono wybrane rodzaje materiałów zmiennofazowych (PCM) oraz ich właściwości pod kątem zastosowań w budownictwie, w tym w technologii betonu. Celem stosowania PCM jako dodatku do świeżego betonu jest umożliwienie przekroczenia określonych barier technologicznych występujących w warunkach klimatu gorącego i suchego, gwarantując schładzanie betonu i tym samym wykonanie niezarysowanych konstrukcji betonowych. Przedstawiono metodologię wielokryterialnego procesu decyzyjnego związanego z wyborem różnych wariantów pielęgnacji betonu w warunkach ekstremalnie suchych z wykorzystaniem stosunkowo nowego narzędzia decyzyjnego w budownictwie jakim jest AHP tj. Analytic Hierarchy Process. Przedstawiono teoretyczne aspekty metody oraz przykład jej praktycznego zastosowania do wyboru najlepszego rodzaju cementu oraz betonu i metody jego pielęgnacji w suchym klimacie syryjskim. Wnioski płynące z przedstawionego artykułu dotyczą dwóch obszarów, tj. celowości stosowania materiałów PCM z przemianą fazową o stosunkowo niskiej temperaturze do regulacji temperatury w dojrzewającym świeżym betonie w suchych warunkach klimatycznych oraz atrakcyjności metody AHP uzasadniającej celowość wyboru alternatywnych metod pielęgnacji młodego betonu w takich warunkach.

Received: 2022-09-19, Revised: 2023-01-17