Implicative Analysis Method and Its Application in Slope Engineering

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Abstract. Slope design must be multi-objective design. In addition to ensuring the slope stability, it is also necessary to achieve other goals such as landscape construction and environmental protection. Slope design is full of various contradictions. Implicative analysis method is a kind of analysis methods in Extenics. The analysis of engineering case shows that using the implicative analysis method in Extenics to assist in dealing with contradictions in slope engineering design can obtain effective solutions and help technicians get rid of excessive dependence on engineering experience and design inspiration.

1. Introduction
Slope is one of the most basic geological environments when highway construction is carried out in mountain area. Even in the traditional design concept, slope protection design is also a complex system engineering, which is full of various contradictions. Under the current background of advocating the new concept of highway design, it is required to achieve the goals of "safety", "beautiful environment", "saving resources", "excellent quality" and "optimal system" of highway through "flexible design" and "creative design"[1]. However, the fact in the actual highway projects is that for a long time, the contradictions in slope design have been described in natural language, lacking effective expression, reasoning and calculation tools. To a large extent, we can only rely on personal experience, inspiration, etc., or copy the "successful" practices of other highways to solve these contradictory problems. The typical phenomenon is that since the implementation of the new concept, there are still a lot of masonry protection slopes in highway projects, which are not coordinated with the surrounding environment, are not natural, beautiful and environmentally friendly. This paper analyzes the actual slope engineering, and shows that using the implicative analysis method in Extenics to assist in dealing with contradictions in slope engineering design can obtain effective solutions and help technicians get rid of excessive dependence on engineering experience and design inspiration.
2. Extenics and Extensible Analysis Principles

Extenics is a subject founded by Chinese scholar Cai Wen in 1983[2]. Extenics uses formalized models to study the extension possibility of things and explore the laws and methods of innovation, so as to solve the contradictory problems (including incompatible problems and antithetical problems) in reality. Extenics method is helpful to get rid of the excessive dependence on experience, inspiration and other individual abilities when solving the contradictory problems [3,4].

The logical cell of Extenics is basic-element, including matter-element "M", affair-element "A" and correlation-element "R"[5]. Basic-element is formally expressed as \( B=(O,C,V) \), where \( O \) is the object, \( C \) is the characteristic, and \( V \) is the value about the characteristic. The value can be a quantitative number or a qualitative description. A basic-element can be one-dimensional or multi-dimensional, and it can also be a parametric basic-element. Extensible analysis principles include divergent analysis principle, correlative analysis principle, implicative analysis principle, expandable analysis principle and conjugate analysis principle.

3. Principle of Implicative Analysis

(1) If basic-element \( B_1 \) is achieved, it must have basic-element \( B_2 \) achieved, written as \( B_1 \Rightarrow B_2 \), which means \( B_1 \) implies \( B_2 \).

(2) If \( B_1 \Rightarrow B_2 \) under condition \( l \), it is called \( B_1 \) implies \( B_2 \) under condition \( l \), written as \( B_1 \Rightarrow (l)B_2 \).

(3) If both \( B_1 \) and \( B_2 \) are achieved, there must have \( B \) achieved, it is called \( B_1 \) AND \( B_2 \) implies \( B \), written as \( B_1 \land B_2 \Rightarrow B \).

(4) If \( B_1 \lor B_2 \) is achieved, there must have \( B \) achieved, it is called \( B_1 \) OR \( B_2 \) implies \( B \), written as \( B_1 \lor B_2 \Rightarrow B \).

(5) If \( B_1 \Rightarrow B_2 \) and \( B_2 \Rightarrow B_3 \), then \( B_1 \Rightarrow B_3 \), or written as \( B_1 \Rightarrow B_2 \Rightarrow B_3 \).

In the above principle of implicative analysis, the basic-element on the left of the symbol "\( \Rightarrow \)" is called the lower basic-element, and the basic-element on the right is called the upper basic-element.

4. Application of Implicative Analysis in Slope Engineering

According to the principle, if the upper goal is not easy to achieve, we can find its lower goal. If the lower goal is easy to achieve, we can be sure that we have found a way to solve the problem.

For example, the soil cutting slope section of a highway is planned to be reinforced by gravity retaining wall, and the wall painting art landscape is planned to be built on the wall. In the traditional sense, retaining wall is only a kind of engineering reinforcement structure, and its structure itself is not suitable for building wall painting art landscape. The following is the analysis process of solving this problem.

The traditional retaining wall only considers its engineering application, that is, supporting retaining soil to ensure slope stability. When it is used as the carrier of painting, it is necessary to consider the accessibility of wall painting, the firmness of color, cleanliness and ornamental.

The matter-element of the goal in this problem is

\[
M_g = \left[ \begin{array}{c}
\text{wallpainting}, \\
\text{carrier}, \\
\text{surface of retaining wall}, \\
\text{artistic effect}, \\
\text{good}
\end{array} \right],
\]

By means of implicative analysis of the matter-element \( M_g \), the goal implicative system of the problem can be obtained:

\[
M_g \Leftarrow M_4 \Leftarrow \left\{ \begin{array}{l}
M_{14} \Leftarrow M_{114} \\
M_{12} \Leftarrow M_{121} \\
M_{13} \Leftarrow M_{131} \land M_{132} \\
M_{14} \Leftarrow M_{141} \\
M_{15} \Leftarrow M_{151}
\end{array} \right.
\]
Among them,

\[ M_1 = \begin{bmatrix}
\text{wall painting,} & \text{carrier,} & \text{surface of retaining wall} \\
\text{paintability,} & \text{good} \\
\text{colour fastness,} & \text{good} \\
\text{cleanliness,} & \text{good} \\
\text{appreciability,} & \text{good}
\end{bmatrix}, \]

\[ M_{11} = (\text{surface of retaining wall, characteristics, smooth}), \]
\[ M_{12} = (\text{retaining wall, shading characteristics, good}), \]
\[ M_{13} = (\text{retaining wall, water repellency, good}), \]
\[ M_{14} = (\text{surface of retaining wall, characteristics, vertical}), \]
\[ M_{15} = (\text{retaining wall, function, providing lighting}), \]
\[ M_{16} = (\text{retaining wall, materials, block stone or concrete}), \]
\[ M_{17} = (\text{overhanging board for shading, position, top of the wall}), \]
\[ M_{18} = (\text{overhanging board for water repellency, position, top of the wall}), \]
\[ M_{19} = (\text{drain hole, position, bottom of the wall}), \]
\[ M_{20} = (\text{surface of retaining wall, dip angle, 70° - 90°}), \]
\[ M_{21} = (\text{lamp holder, position, body of the wall}). \]

Considering the matter-element

\[ M_{16} = \begin{bmatrix}
\text{overhanging board,} & \text{position,} & \text{top of the wall} \\
\text{function,} & \text{shading} \land \text{water repellency} \land \text{lighting installation}
\end{bmatrix}, \]

thus, \( M_{16} \Rightarrow M_{121} \land M_{131} \land M_{151}. \)

From the above analysis, as long as the lowest basic-elements \( M_{111}, M_{132}, M_{141} \) and \( M_{16} \) are achieved, the goal basic-element (uppermost basic-element) \( M_g \) can be guaranteed, that is

\[ M_g \Leftarrow M_i \Leftarrow \begin{cases}
M_{121} \land M_{131} \land M_{151} \Leftarrow M_{16}. \\
M_{132}. \\
M_{141}.
\end{cases} \]

According to this, the concrete retaining wall for artistic painting can be designed, as shown in Figure 1[6].
There should be infinite solutions to a contradictory problem. We can be sure that if we continue to expand the implicative analysis of matter-element $M_g$, and continue to carry out divergent analysis on the objects, characteristics, and values of the characteristics in the correlated basic-elements expanded, we will get more creative schemes of the retaining wall.

5. Conclusions
Implicative analysis method is based on the principle of implicative analysis in Extenics to analyze the goal or condition of a certain contradictory problem, so as to find a way to solve the problem. To sum up, the basic steps of using this method are as follows:

(1) List the basic-elements of slope engineering to be analyzed (usually a slope engineering goal or its sub-goal to be achieved).

(2) According to the known information (design requirements, engineering geological characteristics, etc.) and the principle of implicative analysis, combining with the knowledge of slope engineering, the implicative system is established.

(3) Through the achievement of the lower basic-elements, the upper basic-elements can be achieved, so as to solve the contradictory problem.

Implicative analysis is an auxiliary method which is helpful to get rid of the excessive dependence on experience, inspiration and other individual abilities when solving the contradictory problems. This method has important engineering application value.

Appendix: Extenics symbols and their meanings in this paper

| Symbol | Implication | Symbol | Implication |
|--------|-------------|--------|-------------|
| $B$    | Basic-element | $O$    | Object of basic-element |
| $M$    | Matter-element | $C$    | Characteristic of basic-element |
| $A$    | Affair-element | $\Rightarrow$ | Implicate |
| $R$    | Relation-element | $\wedge$ | AND operation of basic-elements |
| $V$    | Value about the Characteristic of basic-element | $\lor$ | OR operation of basic-elements |

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