考慮流量、坡度及曼寧粗糙係數不確定性之明渠水力斷面設計及優選

Design and Optimization of Hydraulic Section for Open Channel Considering Uncertainties in Flow Rate, Slope, and Manning Roughness Coefficient

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摘　要

利用曼寧公式進行通水斷面設計時，需輸入設計流量、渠底坡度及曼寧粗糙係數。設計流量可經由水文資料分析獲得，但是水文資料具有隨機性，且由於全球氣候變遷影響，使得設計流量的不確定性無法被忽略。此外，因為建造不精確的因素，亦使得渠底坡度及曼寧粗糙係數具不確定性。本研究的目的在於，同時考慮設計流量、底床坡度及曼寧粗糙係數的不確定性，進行梯形渠道斷面的設計及優選。本研究首先在忽略參數不確定性的情況下，回顧最佳水力斷面之理論及簡易的最佳水力斷面設計公式。但若考量參數的不確定性，則無法直接再利用簡易公式，進行最佳水力斷面設計，所以本研究主要著重於利用 Hybrid DE-PSO 啟發式最佳化演算法計算非線性曼寧公式之水深，並驗證其適用性。然後再進一步說明在考慮參數之不確定性下，運用 Rosenblueth 點估計法估，計算水深之平均值與標準偏差，再依據溢流機率，進行梯型渠道斷面設計，並由案例情境得知，考慮參數不確定性之通水斷面設計，亦具有最佳水力斷面的存在。所以本研究最後，建立考慮參數不確定性最佳水力斷面之優選模式，並以 Hybrid DE-PSO 啟發式最佳化演算法求解。結果顯示，對於考慮參數不確定性，每個渠道側坡角度，都具有相對應的最佳水力斷面，且最佳水力斷面之渠底寬與渠高的比值，與渠道側坡角度存在特定關係式，且此特定關係式與傳統不考慮參數不確定性之最佳水力斷面的結果一致。此外，不同的渠道側坡角度，又以渠道側坡角度為 60 度時，具有最大的水力半徑及最小的渠道面積與潤濕周，此結果亦與不考慮參數不確定性之最佳水力斷面的結果相同。另外，隨著溢流機率的變大，最佳水力斷面之渠底寬及渠高皆會變小。案例情境顯示，不考慮參數不確定性之最佳水力斷面的渠底寬及渠高，與考慮參數不確定性溢流機率 0.5 之渠底寬及渠高極為相近；但是，若溢流機率變小，忽略參數不確定性，可能會嚴重低估渠底寬及渠高。另案例情境 2 顯示，當溢流機率為 0.05 時，渠底寬及渠高會分別低估 0.247m 及 0.214m。因此，由以上案例成果可知，在進行水力斷面設計時，需考慮參數之不確定性以避免發生溢流產生淹水災害。

關鍵詞：最佳水力斷面，曼寧公式，優選，不確定性

Abstract

Flow rate, bed slope, and Manning roughness coefficient are required for hydraulic section design of open channel using Manning's formula. The flow rate can be obtained by analyzing the hydrologic data. The uncertainty of flow rate cannot be ignored due to the randomness of hydrologic data and the effect of global climate change. In addition, the construction inaccuracy also makes the bed slope and Manning roughness coefficient uncertain. The goal of this study is to design and optimize the hydraulic section of the trapezoidal open channel, considering the uncertainties in flow rate, bed slope, and Manning roughness coefficient. In this study, the theory of the optimal hydraulic section and a simple equation for designing the optimal hydraulic section are first reviewed by ignoring the parameter uncertainties. However, the simple equation for designing the optimal hydraulic section cannot be directly applied while the parameter uncertainties are considered. Therefore, this study aims to elaborate and verify the application of the Hybrid DE-PSO heuristic optimization algorithm in calculating the water depth of the nonlinear Manning's formula. The model application is performed via the Rosenblueth point estimation method to quantify the mean and standard deviation of the water depth under consideration of the parameter uncertainties. Accordingly, the elaborate hydraulic section of a trapezoidal open channel could be designed based on a given overflow probability. The hypothetical cases present that the optimal hydraulic section could be achieved subject to parameter uncertainties. Therefore, in the last part of this study, the optimization model for hydraulic section design, considering the parameter uncertainties, is established and solved by the Hybrid DE-PSO heuristic optimization algorithm. Also, the model application results show that for each side slope of a trapezoidal open channel, there is a corresponding optimal hydraulic section with a specific relationship between the ratio of the bottom width to the height and the side slope, which is consistent with the results of the traditional optimal hydraulic section without considering the parameter uncertainties. Moreover, among different side slopes, the 60-degree angle of the side slope has the largest hydraulic radius, the smallest channel area, and the wetted perimeter, which is also the same as the result of the optimal hydraulic section neglecting the parameter uncertainties. Furthermore, as the overflow probability increases, the bottom width and height of the optimal hydraulic section become smaller. The hypothetical cases unveil that the bottom width and height of the optimal hydraulic section without parameter uncertainties are very similar to those with the overflow probability of 0.5 but may be severely underestimated when the overflow probability becomes less than 0.5. For example, the bottom width and height are underestimated up to 0.247 m and 0.214 m, respectively, in Case Scenario 2 with the overflow probability of 0.05. As a result, the parameter uncertainties need to be considered for hydraulic section design to mitigate flooding disasters.

Keywords: optimal hydraulic section, Manning's formula, optimization, uncertainty