

冲淤变动型沟谷泥石流防治结构及计算

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摘 要: 本文以平川沟泥石流为例, 基于对冲淤变动型沟谷泥石流基本特性的分析, 遵循“以泄为主、导排结合”的防治原则, 提出了有效治理此类泥石流的汇流—速流结构; 运用地基梁计算理论对速流槽进行了力学分析计算, 比较详细地进行了汇流槽侧墙、锚固桩的内力计算。

关键词: 冲淤变动型; 沟谷泥石流; 治理结构

中图分类号: P642

文献标识码: A

0 引 言

平川沟泥石流位于雅砻江河谷平川河中游的宽阔河谷地段, 河段处于比较强烈的泥石流加积过程中。泥石流形成区主沟谷近于与新构造应力场的主压力方向垂直, 流通区及沉积区主沟道近于与主剪切带平行。根据地貌发育的对抗性原理, 该沟谷不稳定且抗蚀能力不高^[1], 属于典型的冲淤变动型沟谷泥石流。由于地质灾害系统是由诸多自然及人为因子共同构成的一个动态系统, 也是一个远离平衡态的耗散结构系统, 因子之间的相互耦合异变作用产生了熵^[1~2]。近 10 年来, 平川沟泥石流活动逐渐加剧, 年年毁损横穿沟谷的公路路基结构, 造成至少 20 余天的交通中断, 因此, 有效治理该泥石流, 迫在眉睫。本文拟就此类泥石流的治理进行分析。

1 冲淤变动型沟谷泥石流的基本特性

泥石流是沙、砾、水体耦合作用的联合运动, 丰富的地表松散物质、围椅的地貌形态组合及强烈的降雨过程, 构筑了泥石流孕发的基本条件^[2~3]。在山丘地区, 泥石流往往制约着公路建设及公路交通运输。尤其是冲淤变动型沟谷泥石流具有冲击作用强烈、冲击路线变动明显、沉积区比降小等特点, 其长而平缓的淤积区, 对在沉积区横向穿越公路造成冲毁、掩埋等毁损作用^[1]。

2 治理技术

针对冲淤变动型沟谷泥石流具有冲击作用强

烈、冲击路线变动明显、沉积区比降小等特点, 治理方案坚持“以泄为主、导排结合”的泥石流防治原则。

2.1 方 案

拟定其治理结构为汇流—速流结构, 对汇流槽侧墙、固定桩、速流槽等子结构进行结构力学分析计算, 并基于此计算成果进行结构配筋设计。

2.2 地基梁计算原理

运用弹性地基梁计算原理^[4], 即将土体看为半无限弹性体, 速流槽结构相当于弹性地基上的曲线地基梁, 然后等分曲线地基梁, 引入 Winkler 假定, 在每段的中点设置水平及垂直 Winkler 元, 最后分析超静定结构。

3 平川河泥石流治理结构内力计算

3.1 速流槽内力计算

将无限超静定的速流槽结构均等分为 6 份(如图 1)。引入 Winkler 假定, 在每段的中点设置水平及垂直 Winkler 元, 即弹簧为(如图 2)。利用对称性, 过中点 O 取半结构分析, 以右半结构为例, 则此半结构为 6 次超静定(如图 3)。其基本结构为如图 4。

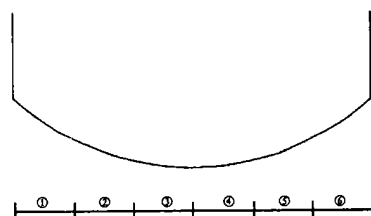


图 1 结构等分示意图

Fig. 1 Part diagram of the structure

收稿日期: 2001-07-29。

基金项目: 本文为交通部通达基金项目、交通部人才基金项目及四川省交通厅科技项目成果之一。

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基本结构不考虑 $X_1, X_2, X_3, X_4, X_5, X_6$, 仅由 X_7, X_8, X_9 构成一个静定结构。

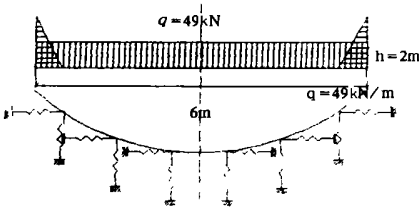


图 2 应用 Winkler 假定的示意图

Fig. 2 Diagram of the structure using Winkler hypothesis

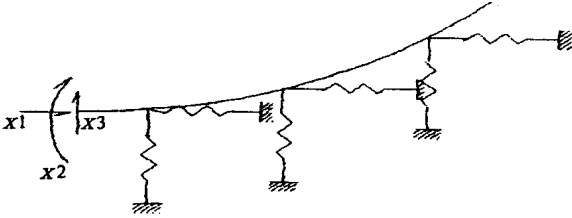


图 3 取半结构示意图

Fig. 3 Semi-structure diagram

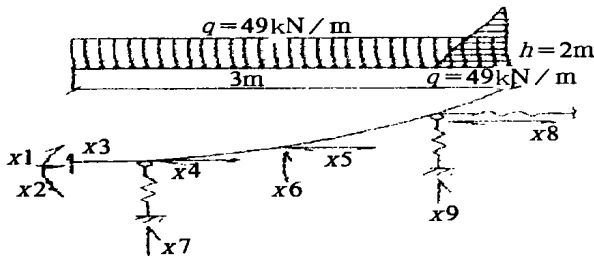


图 4 半结构受力图示

Fig. 4 Load diagram of semi-structure

用混合法解 6 次超静定结构, 建立其力法方程组为

$$\left. \begin{aligned} \delta_{11}X_1 + \delta_{12}X_2 + \delta_{13}X_3 + \delta_{14}X_4 + \delta_{15}X_5 + \delta_{16}X_6 + \Delta_{1p} &= 0 \\ \delta_{21}X_1 + \delta_{22}X_2 + \delta_{23}X_3 + \delta_{24}X_4 + \delta_{25}X_5 + \delta_{26}X_6 + \Delta_{2p} &= 0 \\ \delta_{31}X_1 + \delta_{32}X_2 + \delta_{33}X_3 + \delta_{34}X_4 + \delta_{35}X_5 + \delta_{36}X_6 + \Delta_{3p} &= 0 \\ \delta_{41}X_1 + \delta_{42}X_2 + \delta_{43}X_3 + \delta_{44}X_4 + \delta_{45}X_5 + \delta_{46}X_6 + \Delta_{4p} &= 0 \\ \delta_{51}X_1 + \delta_{52}X_2 + \delta_{53}X_3 + \delta_{54}X_4 + \delta_{55}X_5 + \delta_{56}X_6 + \Delta_{5p} &= 0 \\ \delta_{61}X_1 + \delta_{62}X_2 + \delta_{63}X_3 + \delta_{64}X_4 + \delta_{65}X_5 + \delta_{66}X_6 + \Delta_{6p} &= 0 \end{aligned} \right\} \quad (1)$$

上述方程组的简写形式为

$$\delta_{ij}X_j + \Delta_{ip} = 0 \quad (ij = 1, 2, \dots, 6) \quad (2)$$

δ_{ij} 及 Δ_{ip} 为

$$\delta_{11} = \frac{1}{EI}(\omega_1^1 Y_1^1 + \omega_2^1 Y_2^1 + \omega_3^1 Y_3^1 + \omega_4^1 Y_4^1) = \frac{1188.5373}{EI}$$

$$\delta_{22} = \frac{1}{EI}(\omega_1^1 Y_1^2 + \omega_2^1 Y_2^2 + \omega_3^1 Y_3^2 + \omega_4^1 Y_4^2) = \frac{71.5518}{EI}$$

$$\delta_{33} = \frac{1}{EI}(\omega_1^1 Y_1^3 + \omega_2^1 Y_2^3 + \omega_3^1 Y_3^3 + \omega_4^1 Y_4^3) = \frac{4098.5921}{EI}$$

$$\begin{aligned} \delta_{44} &= \frac{1}{EI}(\omega_1^1 Y_1^4 + \omega_2^1 Y_2^4 + \omega_3^1 Y_3^4 + \omega_4^1 Y_4^4) \\ &= \frac{-8096.1372}{EI} \end{aligned}$$

$$\begin{aligned} \delta_{55} &= \frac{1}{EI}(\omega_1^1 Y_1^5 + \omega_2^1 Y_2^5 + \omega_3^1 Y_3^5 + \omega_4^1 Y_4^5) \\ &= \frac{-2712.5139}{EI} \end{aligned}$$

$$\begin{aligned} \delta_{66} &= \frac{1}{EI}(\omega_1^1 Y_1^6 + \omega_2^1 Y_2^6 + \omega_3^1 Y_3^6 + \omega_4^1 Y_4^6) \\ &= \frac{-13270.6157}{EI} \end{aligned}$$

$$\delta_{11} = \delta_{22} = \frac{71.5518}{EI}$$

$$\delta_{22} = \frac{1}{EI}(\omega_1^2 Y_1^2 + \omega_2^2 Y_2^2 + \omega_3^2 Y_3^2) = \frac{117.1496}{EI}$$

$$\delta_{33} = \frac{1}{EI}(\omega_1^3 Y_1^3 + \omega_2^3 Y_2^3 + \omega_3^3 Y_3^3) = \frac{25445.9625}{EI}$$

$$\delta_{44} = \frac{1}{EI}(\omega_1^2 Y_1^4 + \omega_2^2 Y_2^4 + \omega_3^2 Y_3^4) = \frac{-1540.8485}{EI}$$

$$\delta_{55} = \frac{1}{EI}(\omega_1^2 Y_1^5 + \omega_2^2 Y_2^5 + \omega_3^2 Y_3^5) = \frac{-516.2429}{EI}$$

$$\delta_{66} = \frac{1}{EI}(\omega_1^2 Y_1^6 + \omega_2^2 Y_2^6 + \omega_3^2 Y_3^6) = \frac{-2525.65}{EI}$$

$$\delta_{33} = \delta_{44} = \frac{4098.5921}{EI}$$

$$\delta_{22} = \delta_{33} = \frac{25445.9625}{EI}$$

$$\delta_{33} = \frac{1}{EI}(\omega_1^3 Y_1^3 + \omega_2^3 Y_2^3 + \omega_3^3 Y_3^3) = \frac{209250.9375}{EI}$$

$$\delta_{44} = \frac{1}{EI}(\omega_1^3 Y_1^4 + \omega_2^3 Y_2^4 + \omega_3^3 Y_3^4) = \frac{-77042.4276}{EI}$$

$$\delta_{33} = \frac{1}{EI}(\omega_1^3 Y_1^5 + \omega_2^3 Y_2^5 + \omega_3^3 Y_3^5) = \frac{-25812.143}{EI}$$

$$\delta_{33} = \frac{1}{EI}(\omega_1^3 Y_1^6 + \omega_2^3 Y_2^6 + \omega_3^3 Y_3^6) = \frac{-126282.5}{EI}$$

$$\delta_{44} = \delta_{55} = \frac{-8096.1372}{EI}$$

$$\delta_{22} = \delta_{33} = \frac{-1540.8486}{EI}$$

$$\delta_{33} = \delta_{44} = \frac{-77042.4276}{EI}$$

$$\delta_{44} = \frac{1}{EI}(\omega_1^4 Y_1^4 + \omega_2^4 Y_2^4) = \frac{62830.9881}{EI}$$

$$\delta_{55} = \frac{1}{EI}(\omega_1^4 Y_1^5 + \omega_2^4 Y_2^5) = \frac{21050.7703}{EI}$$

$$\delta_{66} = \frac{1}{EI}(\omega_1^4 Y_1^6 + \omega_2^4 Y_2^6) = \frac{102988.1132}{EI}$$

$$\hat{q}_1 = \hat{q}_5 = \frac{-2712.5139}{EI}$$

$$\hat{q}_2 = \hat{q}_5 = \frac{-516.2429}{EI}$$

$$\hat{q}_3 = \hat{q}_5 = \frac{-25812.142}{EI}$$

$$\hat{q}_4 = \hat{q}_5 = \frac{21050.7703}{EI}$$

$$\hat{q}_5 = \frac{1}{EI}(\omega_1^5 Y_1^5 + \omega_2^5 Y_2^5) = \frac{7052.8086}{EI}$$

$$\hat{q}_6 = \frac{1}{EI}(\omega_1^5 Y_1^6 + \omega_2^5 Y_2^6) = \frac{34504.9343}{EI}$$

$$\hat{q}_1 = \hat{q}_6 = \frac{-13270.6157}{EI}$$

$$\hat{q}_2 = \hat{q}_6 = \frac{-2525.65}{EI}$$

$$\hat{q}_3 = \hat{q}_6 = \frac{-126282.5}{EI}$$

$$\hat{q}_4 = \hat{q}_6 = \frac{102988.1132}{EI}$$

$$\hat{q}_5 = \hat{q}_6 = \frac{34504.9343}{EI}$$

$$\hat{q}_6 = \frac{1}{EI}(\omega_1^6 Y_1^6 + \omega_2^6 Y_2^6) = \frac{168810.8333}{EI}$$

$$\begin{aligned} \Delta_{1p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^1 + \omega_2^{P1} Y_2^1 + \omega_3^{P1} Y_3^1 + \omega_4^{P1} Y_5^1 + \\ &\quad \omega_6^{P2} Y_6^1 + \omega_7^{P2} Y_7^1) \\ &= \frac{4.232 \times 10^{10}}{EI} \end{aligned}$$

$$\begin{aligned} \Delta_{2p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^2 + \omega_2^{P1} Y_2^2 + \omega_3^{P1} Y_3^2 + \omega_4^{P1} Y_5^2 + \\ &\quad \omega_6^{P2} Y_6^2 + \omega_7^{P2} Y_7^2) \\ &= \frac{9.959 \times 10^9}{EI} \end{aligned}$$

$$\begin{aligned} \Delta_{3p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^3 + \omega_2^{P1} Y_2^3 + \omega_3^{P1} Y_3^3 + \omega_4^{P1} Y_5^3 + \\ &\quad \omega_6^{P2} Y_6^3 + \omega_7^{P2} Y_7^3) \\ &= \frac{-4.436 \times 10^{10}}{EI} \end{aligned}$$

$$\begin{aligned} \Delta_{4p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^4 + \omega_2^{P1} Y_2^4 + \omega_3^{P1} Y_3^4 + \omega_4^{P1} Y_5^4 + \\ &\quad \omega_6^{P2} Y_6^4 + \omega_7^{P2} Y_7^4) \\ &= \frac{-3.431 \times 10^{11}}{EI} \end{aligned}$$

$$\begin{aligned} \Delta_{5p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^5 + \omega_2^{P1} Y_2^5 + \omega_3^{P1} Y_3^5 + \omega_4^{P1} Y_5^5 + \\ &\quad \omega_6^{P2} Y_6^5 + \omega_7^{P2} Y_7^5) \\ &= \frac{-1.696 \times 10^{10}}{EI} \end{aligned}$$

$$\begin{aligned} \Delta_{6p} &= \frac{1}{EI}(\omega_1^{P1} Y_1^6 + \omega_2^{P1} Y_2^6 + \omega_3^{P1} Y_3^6 + \omega_4^{P1} Y_5^6 + \\ &\quad \omega_6^{P2} Y_6^6 + \omega_7^{P2} Y_7^6) \\ &= \frac{1.873 \times 10^{10}}{EI} \end{aligned}$$

用 Matlab 软件解此方程组得

$$X_1 = 0 \text{ kN}, X_2 = 0 \text{ kN}, X_3 = 0 \text{ kN},$$

$$X_4 = -2.35 \text{ kN}, X_5 = -0.809 \text{ kN},$$

$$X_6 = 1.599 \text{ kN}$$

由此,解得结构受力(如图 5)。

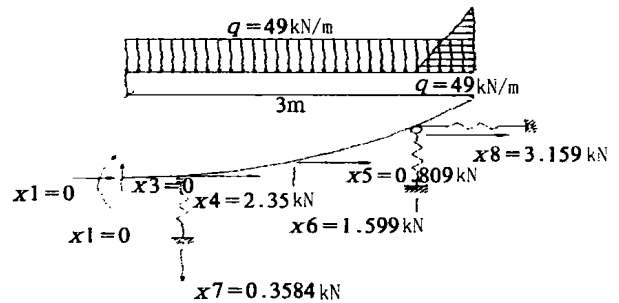


图 5 半结构受力图示

Fig. 5 Load diagram of semi-structure

计算速流槽内力如图 6。

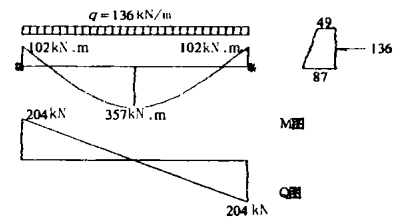
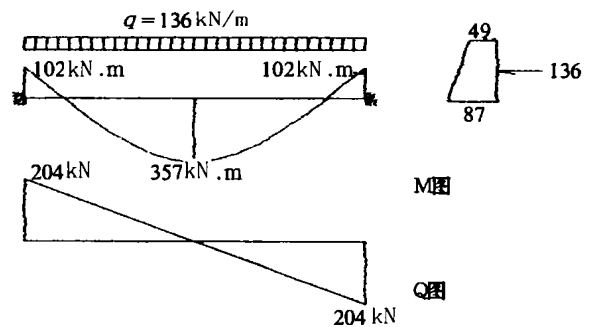


图 6 速流槽内力图示

Fig. 6 Internal force of the express flow trough (EFT)

3.2 侧墙内力计算(如图 7)



注:因作用于侧墙上的荷载垂直方向呈梯形分布,

故取其合力 $q = 136 \text{ kN/m}$

图 7 侧墙内力图示

Fig. 7 Internal force of the lateral wall

3.3 计算桩的内力

经分析, 可将此桩简化为一次超静定结构, 纵、横两向分别计算所承受的内力。(沿泥石流流走向为纵向, 垂直于泥石流走向为横向)

3.3.1 纵向桩内力

由于桩的一侧是水库, 故桩受到土压力、水压力及泥石流带来的冲击荷载作用(如图8)。

解此超静定结构

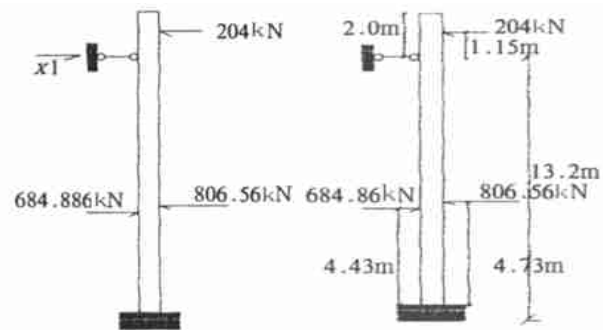


图 8 桩的基本体系
Fig. 8 Basic model of the pile

图 9 桩的受力图示
Fig. 9 Load model of the pile

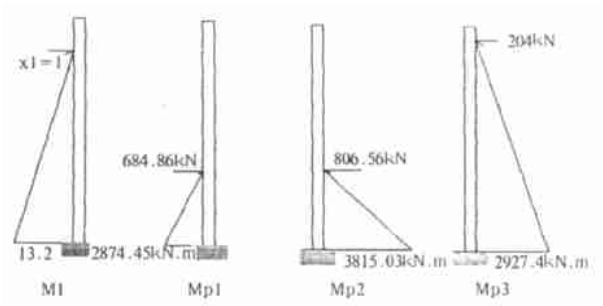


图 10 解超静定的弯矩图
Fig. 10 Moment diagram of solving the pile with multi-restriction

$$\delta_1 = \frac{1}{2EI} \times 13.2 \times 13.2 \times \frac{2}{3} \times 13.2 = \frac{766.656}{EI}$$

$$\Delta_{P1} = -\frac{1}{2EI} \times 4.43 \times 2874.45 \times 11.7233 = -\frac{74641.37}{EI}$$

$$\Delta_{P2} = \frac{1}{2EI} \times 3815.03 \times 4.73 \times 11.6233 = \frac{104938.5741}{EI}$$

$$\Delta_{P3} = \frac{1}{2EI} \times 2927.4 \times 14.35 \times 8.4167 = \frac{176784.4663}{EI}$$

$$X_1 = -\frac{\Delta_{P1} + \Delta_{P2} + \Delta_{P3}}{\delta_1} = -270.11 \text{ kN}$$

据计算所得画出桩的内力图(图 11)

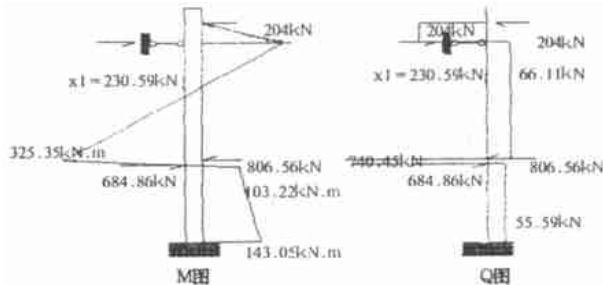


图 11 桩的内力图
Fig. 11 Internal force of the pile

3.3.2 横向内力

由于桩的两侧土压力抵消, 故桩只承受冲击荷载(如图 12)。

解此超静定结构

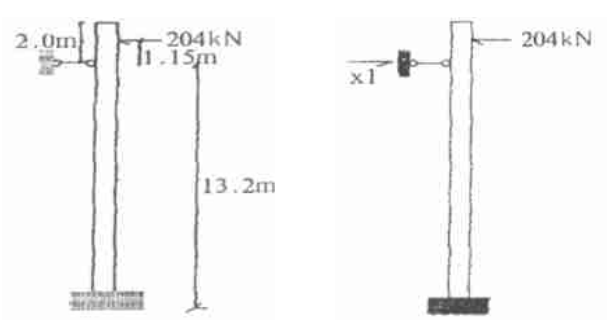


图 12 桩的受力图示
Fig. 12 Load diagram of the pile

图 13 基本体系
Fig. 13 Basic model

$$\delta_1 = \frac{1}{2EI} \times 13.2 \times 13.2 \times \frac{2}{3} \times 13.2 = \frac{766.656}{EI}$$

$$\Delta_p = \frac{1}{2EI} \times 2927.4 \times 14.35 \times 8.4167 = \frac{176784.4663}{EI}$$

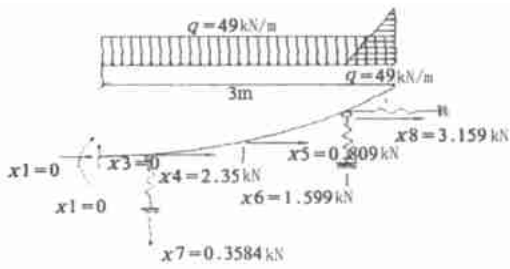


图 14 解超静定的弯矩图
Fig. 14 Moment diagram of solving the pile with multi-restriction

$$X_1 = -\frac{\Delta_p}{\delta_1} = -230.59\text{kN}$$

据计算所得画出桩的内力图(图15)。

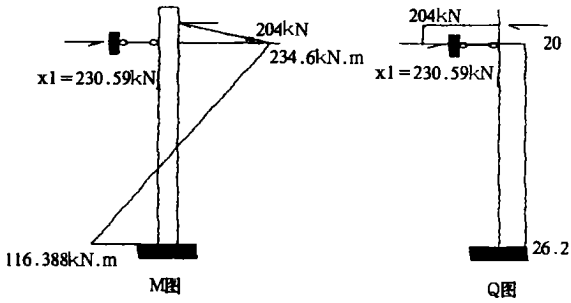


图 15 桩的内力图

Fig. 15 Internal force of the pile

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Structure and Calculation to Prevent Highway from Debris Flow with Strong Deposition and Impaction

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Abstract: Taking debris flow at Pingchuan valley as an example, the authors analyze the basic special environmental conditions, prevent principal and prevent structures in view of structure mechanics and elastic foundation beam theory in this paper. The paper proposes the effective harness structure, named converging and rapid flow structure, which combined with guiding and drainage ideas. The rapid flow trough employs the calculation theory and method of elastic foundation beams to calculate the structure force. In addition, the paper have given a fairly interior force calculation to lateral wall and anchorage for every parts of the structures.

Key words: deposition and impaction; valley debris flow; harness structure