MODEL CALIBRATION OF LANDSLIDE BOUNDARY VALUE PROBLEMS BY INVERSE ANALYSIS

Michele Calvello

Department of Civil Engineering, University of Salerno, Fisciano, Italy

The paper presents an inverse analysis procedure used as a tool to calibrate the numerical models of two very different landslides: a slow moving active slide characterized by very slow movements occurring within a narrow band of weathered bedrock; and a fast moving debris flow characterized by a relatively short propagation distance. In the first case, the procedure is used to update, with time, the landslide model using available groundwater and displacements monitoring data. In the second case, the study focuses on the key role played by the field observations used to set up the inverse analysis and to assess the reliability of the numerical simulations. In both cases, results already published by the Author are presented alongside with more recent research findings.

Keywords: inverse analysis, landslide, modelling, field observations

INTRODUCTION

Landslide boundary value problems are often difficult to model. The accuracy of the model predictions are related to factors such as: the boundary value problem schematization (e.g., geometry, stratigraphy, soil constitutive laws); the estimates of the model input parameters; the initial and boundary conditions. To improve the reliability of landslide models, calibration is often conducted performing back-analyses of landslide case studies for which monitoring data are available. Inverse analysis techniques may be very helpful to this purpose. The major advantage of inverse analysis approaches to calibrate model input parameters is the automatic and objective calculation of the parameter values that produce the best fit between measured data and computed results. The paper presents the case studies of two very different landslides, for which a versatile inverse analysis algorithm, based on a multiparametric linear regression method, is effectively used to calibrate the numerical models of the phenomena.

ADOPTED INVERSE ANALYSIS PROCEDURE

Inverse analysis works in the same way as a non-automated calibration approach: parameter values and other aspects of the model are adjusted until the model’s computed results match the observed behavior of the system. In this study, model calibration is conducted adopting a procedure (Calvello, 2014) based on a modified Gauss-Newton regression method (Poeter and Hill, 1998) that minimizes a weighted least-squares objective function, $S(b)$:

$$S(b) = (y - y'(b))^T \omega (y - y'(b)) = e^T \omega e$$  

(1)
where: $b$ is the vector of the parameters being estimated; $y$ is the vector of the observations being matched by the regression; $y'(b)$ is the vector of the corresponding computed values; $\omega$ is the weight matrix, being the weight of every observation taken as the inverse of its error variance; $\varepsilon$ is the vector of residuals.

The regression needs, at any given iteration, the computation of a sensitivity matrix using a perturbation method and, thus, multiple runs of the numerical model. Two convergence criteria are used to end the optimization. Weights are assigned to the observations for two purposes: to reduce or increase the influence of some observations; to produce weighted residuals that have the same units. A commonly used indicator of the overall magnitude of the weighted residuals is the model error variance, $s^2$:

$$s^2 = \frac{S(b)}{ND-NP}$$

where: $S(b)$ is the objective function; ND is the number of observations; NP is the number of estimated parameters. More details on the procedure adopted herein can be found in Calvello (2014).

**SLOW-MOVING LANDSLIDE CASE STUDY**

The case study is a well-studied active landslide located in central Italy characterized by a soil profile consisting of three overlying layers: a marly clay bedrock, a weathered band of the bedrock, wherein most of the landslide movements occur, and a clayey silt colluvial cover (Bertini et al., 1984). In situ data include observations from one pluviometric station, 12 piezometric cells and six inclinometers. Calvello et al. (2008) analyzed this case study proposing an inverse analysis procedure comprising a seepage model and a kinematic model relating landslide movements along pre-existing slip surfaces to rainfall data. They were able to adequately simulate, for the 3-year long period under study, both the pore pressure fluctuations in all installed piezometers and the kinematics of the movement along the slip surface. As an example of the obtained results, Fig. 1 presents the head contour lines of the calibrated seepage model at the end of the numerical simulation and the comparison between recorded and computed piezometric levels. For some of the piezometers (A2, B3, B4, C7, G11, G12) the fit is almost perfect, but even for the rest of them the fit is satisfactory. The adopted modelling approach, which combines the observational method and inverse analysis techniques to update, with time, the model of a boundary value problem using available monitoring data, may be called “observational modelling” (Calvello, 2017).

**FAST-MOVING LANDSLIDE CASE STUDY**

The case study is a debris flow characterized by a relatively short propagation distance which occurred in Hong Kong in 2005 (Knill 2006). Following up on a previous study by Cuomo et al. (2015), this study focuses on the role played by the field observations used to set up the inverse analysis and to evaluate the reliability of the numerical simulations. Several sets of observation are herein used. They all refer to soil thickness values at the end of the propagation stage, yet they differ in the both location and number of the adopted values. The numerical analysis is performed using GeoFlow_SPH (Pastor et al., 2009) and schematizing slope
Monitoring data. In this case, it is evident that the variation in error variance, for different pairwise combinations of the four parameters’ values, is used to define the parameters playing a relevant role in the performance of the model. In this case, it is evident that only two parameters, \( \varphi'_b \) (basal frictional angle) and \( P_{rw} \) (ratio between initial basal pore-water pressure and liquefaction pressure), significantly influence the numerical results of the model.

Fig. 1 Comparison between computed and measured head (m a.s.l.) at the location of the piezometers (modified from Calvello et al., 2008).
CONCLUSION

A versatile inverse analysis algorithm has been effectively used to calibrate the numerical models of the two landslide boundary value problems: a slow moving active slide and a fast moving debris flow. In the first case, observational modelling is possible, i.e. inverse analysis techniques can be used to update, with time, the landslide model using available monitoring data. Indeed, as time passes and more monitoring data are available, the update of the numerical model allows more reliable model predictions of the future landslide behavior. In the second case, the adopted calibration procedure proved successful in calibrating the model parameters of a complex rheological law once the most suitable observation sets were selected based on a simpler rheological law adopting a single input parameter.

REFERENCES