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# Characterization of the instability mechanisms affecting slopes on carbonatic Flysch: Alicante (SE Spain), case study

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ABSTRACT

The studied Flysch sequence of Alicante occupies a widely populated area crossed by main communication routes. The slopes existing on this area usually suffer slope instabilities that cause substantial damage and a very high maintenance cost. In order to assess the type of instability mechanisms affecting these heterogeneous carbonatic slopes, in this paper a wide inventory of 194 Flysch rock slopes has been performed, reporting the existing lithologies, their competence and their relative arrangement and the geometrical relationship between bedding and the slope and the associated instability mechanism. All these data have been jointly used for performing an instability mechanisms characterization. For systematically characterizing the wide type of complex rock exposures existing in the study area, they are divided into basic units referred as lithological pattern columns to which the different observed instability mechanisms are associated. Inventoried instability mechanisms are diverse and sometimes are combined with each other. Rockfalls are a very common instability mechanism associated to the differential weathering and sapping of the marly lithologies which are present in a wide number of geometrical combinations. The other instability mechanisms closely depend on the combination of the geometrical and lithological parameters. Therefore, this work provides a new basic tool which can be easily used during preliminary project stages for knowing the instability mechanisms which can affect rock slopes excavated on carbonatic Flysch heterogeneous geological formations.



## 1. Introduction

The term Flysch, introduced in the geological literature by the Swiss Bernhard Studer (1827), referred to a type of lithology, specifically to an alternating series of sandstones and schists with subordinate presence of breccias, conglomerates and limestones of the Upper Cretacic of the Swiss region of Siemmenthal. Etymologically, this word of German origin refers to the landslides of the areas where these geological formations were available. In contrast to later use, Studer (1827) defined the Flysch petrologically and not as a specific stratigraphic formation. Currently, from a geological point of view, the term Flysch, not without controversy, is associated to other terms with clear tectonic, stratigraphic and/or sedimentological connotations as wildflysch, turbidite, slope basin, olistostrome, olistolithe, sedimentary mélanges, slumped margin, marine debris flow, submarine fan, abyssal plain, pelagic deposits, slope deposits, delapsional deposits, etc.

This paper does not attempt to enter the scientific debate on the terms previously introduced. Although strictly the term Flysch should refer to a sequence of thick, clastic, resedimented, sinorogenic and of deep marine origin lithologies, from a more general point of view and even more engineering, the term used in this paper refers to the lithological complex sequence defined as a Flysch-like sedimentation, with turbidites, slumps and olistrostromes. For a more detailed description of the previous mentioned sedimentological concepts, vital importance for understanding the complexity of these formations, next works can be consulted: Kuenen and Migliorini (1950), Flores (1955), Bouma (1962), Jaccobacci (1965), Sanders (1965), Hoedemaeker (1973), Esteban and Santanach (1974), Mutti et al. (2003), Kendall (2006) and Mutti et al. (2009).

The main scope of this paper is to allow characterizing the main instability mechanisms affecting rock slopes on Flysch of Alicante. Furthermore, the proposed characterization may be applied for studying other areas with similar heterogeneous geological formations. The proposed methodology is based on the recognition of the relative position of the existing lithologies, which present different competences, and the geometrical relationship between the slope and the bedding, that condition the type of failure/s associated to the slopes. The obtained relations may be used during early project stages as a tool for designing cur-slopes.

Due to their geological complexity, these formations present high difficulties in order to be characterized from a geomechanical behaviour point of view. Some attempts have been carried out for applying rock mass classification systems to these complex rock masses by different researchers. Marinos and Hoek (2001) conducted an adaptation of the Geological Strength Index (GSI) (Hoek, 1994) for Flysch rock masses

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and Marinos et al. (2005) reviewed the GSI index, analysing its applicability and limitations. They pointed out that when there is a clear predominance of one set of discontinuities GSI index application is more difficult given that the isotropic character of the rock mass cannot be guaranteed. Ünal (1996) modified the original RMR classification (Bieniawski, 1984) adapting it to weak, stratified, anisotropic and clayey rock masses (M-RMR). Popiolek et al. (1993) proposed a geotechnical classification for Flysch rock masses named Geotechnical Flysch Rock Mass Classification (KF) based on Rock Mass Rating (RMR) for characterizing underground excavations in Carpatian Flysch brechoid rocks. Morales et al. (2004) performed a geomechanical classification of Flysch formations of the NE of Spain, proposing a classification of the rock masses as a function of widely known geomechanical indexes GSI and RMR. Although all these geomechanical characterisation systems can be conveniently applied to the slopes existing in the area of study, neither of them is focused on the determination of the instability mechanisms affecting a specific slope.

Pantelidis (2009) argued that the type of failure of rock cuttings is indissolubly connected, among others, with the presence of discontinuities. The orientation of discontinuities relative to slope face largely controls the possibility of unstable conditions or excessive deformations developing and therefore, it is a parameter of significant importance for the structurally controlled instabilities. For instance, Selby (1980) proposed the Rock Mass Strength (RMS) classification system which considers the orientation of the dominant set joints relative to slope surface and state of rock weathering in the basic rock mass rating. However, its applicability to heterogeneous slopes is low and do not provide the type of instability mechanism associated to a slope under study. Pierson et al. (1990) developed the Rockfall Hazard Rating System (RHRS), a semi-quantitative system for ranking rockfall hazard along long segments of track. Although the most frequent instability mechanism observed on the study area is precisely rockfall, RHRS is far from the scope of this work. Thus, in most of the rock mass classification systems, included those used for Flysch rock masses, no reference exists to the common types of instability mechanism (planar, toppling, etc.) and when the mechanism is considered (e.g. in Slope Mass Rating geomechanical classification, SMR; Romana, 1985) instability mechanisms induced by differential erosion at slope faces are not included in any system. Other researchers (e.g. Gökçeoğlu et al., 2000; Nicholson, 2003, 2004) focused on the evolution and weathering of rock masses. This is a key question for Flysch rock masses where some instabilities present a clear evolutive process.

The paleogen series studied on this work occupies the littoral and pre-littoral area of Alicante province comprised between Aguas de Busot at West and the Mediterranean Sea at East and Alicante City at South and Benidorm at North. This area is densely populated and three main communication routes (AP-7 and N-332 highways and FGV railway; Figure 1) run through the carbonatic Flysch materials. The slope instabilities affecting these routes, such as rockfalls, planar slides, toppling and buckling failures, rotational slides, ravelling and erosion cause a high maintenance cost. Furthermore, the coastline fringe is dominated by steep cliffs urbanized in its crown that are frequently affected by the same slope instabilities. This fact also supposes an important risk for the beach bathers that usually visit the beaches located at the toe of the coast cliffs. As a consequence, because the understanding of the slope failure mechanisms is essential for the later design of the corrective and preventive correction measures, in this work a detailed description of the different slope instabilities affecting the carbonatic Flysch formations is performed. Moreover, the lithological and geometrical parameters are related with the instability processes through a systematic characterization.

The paper is structured as follows. In the second section the regional geological setting and litho-stratigraphic setting of the study area are described. Section 3 describes the employed methodology. Section 4 is devoted to show the main results of this work and includes a characterization of lithological units based on their competence, a lithological characterization of Flysch rock exposures and a description of the observed slope instability mechanisms and

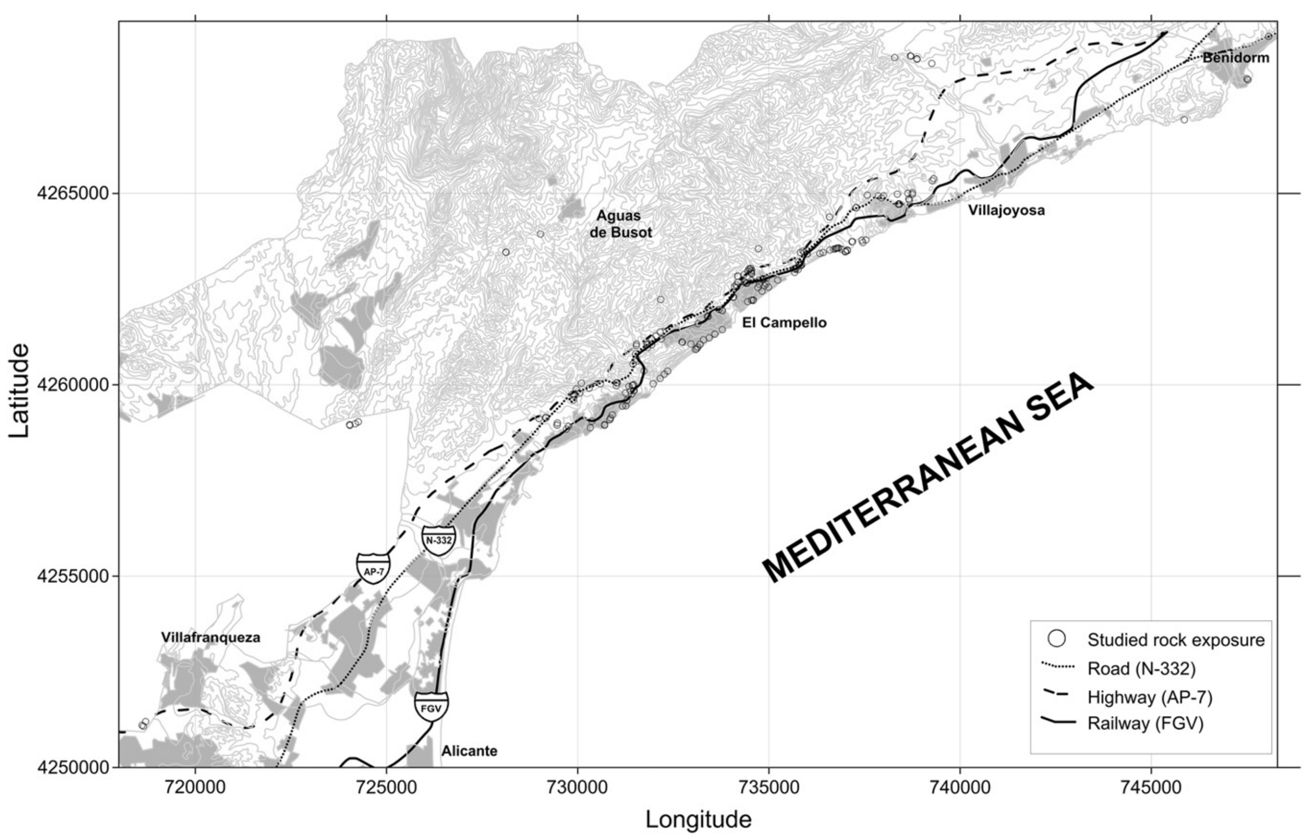


**Fig. 1.** Location of the studied rock slopes.