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FLOOD HAZARD FACTORS AND INDEXES FOR ROAD STREAM CROSSINGS IN EPHEMERAL CHANNELS. STUDY APPLIED TO THE COASTAL SOUTHERN AREA OF THE MURCIA REGION

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An important natural hazard affecting to the road networks and to the traffic in semiarid areas is caused by the flood waters in road stream crossings. The main aim of this paper is to propose a methodology for evaluating the hazard of road-ephemeral channel crossings, from exposition levels and hydrological, hydraulic and morphological criteria. This approach has been applied to the coastal southern area of the Murcia Region, obtaining 54 maps of hazard indicators for road-ephemeral channel crossings under different hydrological conditions.

I. INTRODUCTION

Ephemeral water channels are frequently affected by road structures crossing them. If good drainage is not ensured along road-crossings, flood waters can be abruptly interrupted and adopt highly critical regimes which could alter the morphological conditions of the channel and increase the danger around these structures. The passing of a road across gullies or ephemeral channels (‘*ramblas*’) should be carried out ensuring adequate drainage to avoid complete or partial destruction of the structure, prevent flooding and reduce to a minimum the negative environmental impact caused by changes imposed on the surface run-off. Flooded and waterlogged roads occur when the amount of water arriving on the road is greater than the capacity of the drainage facilities that take it away. Badly-drained flood waters affect road use capacity and when they overflow occupying the road surface they can become a serious hazard for traffic.

The prevention of these negative impacts has been progressively integrated into the design and construction of road infrastructures in Spain ever since the introduction of the pertinent legislation (RDL 1302/86) for evaluating its environmental impact. Similarly, drainage design has been gradually changing in order to incorporate preventive and corrective measures for such impacts in accordance with several specific road drainage laws introduced in this country. Specifically, through the introduction of the Order of 21st of June 1965, Road Guideline 5.1-IC on «Drainage» was published. More recently, on 14th May 1990, in view of the technical advances achieved, the Spanish Highways Authority proceeded to revise the text of this Guideline, focusing on road surface drainage, and introduced Road Guideline 5.2-IC on «Surface drainage». The aim of this guideline has been to provide the rules and recommendations for adequately planning, building and conserving the elements of road surface drainage.

This study will analyze the effectiveness of *road-crossing drainage structures* in ephemeral streams based on real situations observed *in situ* and, whenever possible, after consulting drainage work projects, regardless of the extent to which the aforementioned laws have been fulfilled. A *methodological proposal to formulate* flood hazard indexes *for road stream crossings is shown from hydrological,* hydraulic and *morphological criteria and from exposure factors*. The studied road-stream crossings are located in ephemeral channels (locally denominated as «ramblas») on the south coast of the Murcia Region (Spain), where this type of hazard is clearly related to the torrential dynamics of the local fluvial systems and the presence of a dense network of roads often *badly drained*.

II. HAZARD FACTORS IN ROAD-STREAM CROSSINGS

2.1. General factors indicating hazard

A first general valuation of the dangerousness - vulnerability of the road-stream crossings in ephemeral channels needs to know: a) the exposure of the road infrastructures and the use of them; b) the degree of inefficiency of the drainage works (design *capacity of* the cross-*drainage structures minus peak discharges for different return periods or discharges associated to hydraulic geometry* relationships); c) the type of stream crossings on ephemeral channels; and d) the risk of blockage in drainage structures.

2.2. Hydrological and hydraulic hazard indicators

The efficiency of the drainage works depends basically on the combination of two factors: i) the return-period of the flows that they can evacuate in relation with its potential damages; and ii) the susceptibility to a total or partial obstruction in the drains, because of the technical characteristics of design and construction, and / or due to a high geomorphologic activity in the fluvial system.

The use of return period discharges considered to be dangerous in the hydraulic legislation can be replaced by the application of discharges associated with hydro-geomorphological thresholds. Directive 2000/60/CE of the European Parliament and of the Council, which establishes a Community framework for water policy action, highlights the importance of these types of criteria in any type of action and strategy developed for the restoration, protection and management of fluvial systems. The choice of discharge thresholds imposed by the «*bankfull*» and *«flood prone area»* hydraulic geometry levels is an excellent way to analyze the hydraulic and hydromorphological hazard in ephemeral channels such as those of the present study. In this type of system the degree of uncertainty obtained using hydraulic geometry parameters which can be directly measured in the field is lower than that of discharge predictions based on probability distributions of maximum daily rainfall.

2.3. Geomorphological factors causing hazardous situations

The construction of linear infrastructures crossing ephemeral channels is followed by a process of morphologic and hydraulic adjustment causing *changes in bed stability* up to achieving new dynamic equilibrium. Bed instability combined with a high bed load capacity can threaten the own stability of the road infrastructures and its drainage devices, causing a serious danger for those who use them. Bed load, in itself, also constitutes a purely influential factor on the obstruction rhythm of the drains. The hydraulic regime of the dominant discharges in ephemeral channels is enough to move and displace considerable quantities of material. High rates of bed-load transport in low water crossings increase significantly the hazard of floodwaters.

III. NATURAL HAZARD INDEXES FOR ROAD-STREAM CROSSINGS

3.1. General Hazard Index for road-stream crossings (GHI_{CR})

A first approach has been chosen in order to develop a General Hazard Index for road-stream crossings, based on the combination of three data layers: coverage of road network specifying classes of roads, vector data of channel reaches showing overflow or flood hazard, and vector data of road sections with different category and daily traffic intensity (DTI). From these criteria levels of exposure have been established. The road classification proposed by the Highways Authority of the Autonomous Community of Murcia Region has been used. The traffic intensity data correspond to DTI's gauging of vehicles and to DTI's values of heavy traffic obtained for 2007 by the same Regional Administration. For weighting the road category, specific weight is assigned more to the primary roads, a value of 6 being given to the highways, 5 to the national roads, 4 to the autonomous roads of 1er order, 3 to the autonomous roads of 2º order, 2 to the local and secondary roads (autonomous of 3er order) and 1 to the local ways and cross-streets.

$$I_{EXP} = (((ADTI + ADTI_{hv})/2) + C_{road}) / 12 \quad (1)$$

where I_{EXP} = Exposure Index, ADTI = *Average Daily Traffic Intensity*; $ADTI_{hv}$ = A*verage Daily Traffic Intensity* of heavy vehicles; C_{road} = road category, and 12 is a constant value which allows to define the range of variation between 0 y 1. Finally General Hazard Index for road-stream crossings is calculated (GHI_{CR}) for floodwater stages, being the result of multiplying the Exposure Index by Inefficiency Index of drainage structures. According to the type of crossing and drainage work this index can show the following expressions:

a) For high road crossings drained by bridges and long-span bridges:

$$GHI_{CR} = (I_{EXP} \cdot 2) \cdot INEF_B{}^* \quad (2a)$$

$$INEF_B = 1/ EFM_B \; ; \qquad INEF_B^* = INEF_B^{\,1/INEF} \qquad (2b)$$

where $INEF_B$ = Inefficiency Index; $INEF_B$* = Inefficiency Index rectified from a *weighting factor* of potential function; EFM_B = Mean Degree of Inefficiency.

b) For *culvert stream-crossings*:

$$GHI_{CR} = (((I_{EXP}) \cdot 2) + (V \cdot H))/2) \cdot INEF_{CUL} \qquad (3a)$$

$$INEF_{CUL} = 1 - EF_{CUL} \qquad (3b)$$

This index can be estimated for bankfull stages from velocity (V) and height (H) in bankfull flows ($EF_{CUL} = Q_{CUL} / Q_{BK),}$ or for conditions of «flood-prone area» using data on velocity and level of overflow waters covering *adjacent floodplain parts*, being $EF_{CUL} = Q_{CUL} / Q_{FP}$.

EF_{CUL} = Degree of efficiency for culverts; $INEF_{CUL}$ = Inefficiency Index for pipes and culverts. The BK and PR subindexes are referred to the levels of bankfull discharges (formative discharges) and flows filling flood-prone area (active floodplain).

c) For ford crossings in ephemeral channels:

$$GHI_{CR} = (((I_{EXP} \cdot 2) + (V \cdot H))/2) + (W/1000) \qquad (4)$$

where W is the flow width on the road reach affected. Besides the proposed intervals, the epithet of high dangerousness can be used in crossings of this type when ADTI > 1.000 vehicles / day (class 3), V · H = 0.5, and 0.4 < GHI_{CR} <0.7; and of very high dangerousness when ADTI > 1.000 vehicles/day (≥ clase 3) and V·H ≥ 0.5.

3.2. Hydrological and Hydraulic Hazard Index (HI_H)

This index has been developed for two types of crossing in ephemeral streams: i) *culvert stream-crossings,* and ii) *ford crossings*.

a) For *road-crossing drainage culverts*:

$$HI_H = (INEF_{CUL} \cdot (V \cdot H)) + qr \qquad (5)$$

where qr is the unit overflow discharge over road.

b) *For ford crossings*:

$$HI_H = (V \cdot H) + (W/1000) \qquad (6)$$

where W is the width of the flow on the affected road reach.

3.3. Geomorphological Hazard Index (HI_G)

For formulating this index different hydraulic and morphological variables have been used. Under high bridges and long-span bridges the HI_G Index can be associated with linear scouring and, therefore, with granular susceptibility to processes of bed incision and with different degree of bed armouring. The transitory scouring is estimated from the critical flow velocity according the Neill's method. In this case, both variables, critical flow velocity and transitory scouring, are indicators of geomorphological hazard since they can affect the foundations of bridge piers causing instability to the whole structure.

For *culvert stream-crossings and ford reaches the* HI_G is related to the unit bed load, the Relative Bed Instability Index (RBI) and the Relative Bed Stability Index (RBS). In addition, for culvert stream-crossings an Obstruction Hazard Index (HI_{OBS}) has been applied as a variable dependent on the Index of Obstacles (I_{OBSTA}) and the potential transport of coarse sediments.

IV. OBTAINING MAPS OF HAZARDS FOR ROAD-STREAM CROSSINGS

This methodological proposal has been applied to the Mediterranean coast of the Region of Murcia (Spain), obtaining a total of 54 maps of hazard indicators for road-stream crossings under different hydrological conditions, especially at bankfull stage and flood-prone area. 12 maps represent the General Hazard Index for road-stream crossings with bridges, as well as the principal variables used in its estimation (capacity and degree of hydraulic efficiency), corresponding to peak discharges for different return periods. Other 15 maps show the Geomorphological Hazard Index for the same return periods and the variables from which this index has been deduced (critical velocity, transitory scouring and granular susceptibility to processes of bed incision).

Most bridges in the area (63%) have sufficient capacity to drain flows with return periods up to 500 years. According to its average degree of efficiency in floods estimated for 100, 200 and 500 year return periods, the percentage of bridges with inefficient drainage is 16%. In many cases, the transitory scour is very high, but the net erosion rates are scarcely significant and the stability of the structures does not turn out to be generally affected.

Finally 22 maps are referred to the GHI_{CR}, HI_H and HI_G indexes applied to *culvert stream-crossings at* bankfull stages y flood prone areas. In this type of crossings, the hydraulic hazard is closely related to the geomorphologic dynamics of the immediate reaches upstream. The analysis of results allows to obtain the following considerations:

1) Crossings with insufficient culvert capacity at bankfull stage represent 23.5 %. The most serious cases correspond to the culverts placed in *gravel-bed* channels which have a steeper slope and high bed load. 2) For most of crossings (88.2 %) in flood prone areas the culverts drain discharges far below of those which circulate along main channels and adjacent floodplains, causing overflow and runoff over road. 3) Critical situations provoked by sediment contributions, bed instability and particles mobility are produced during floodwaters of which hydraulic radius and flow velocity increase sensitively its bed load capacity. 4) The ford crossings in ephemeral channels («*ramblas*», ravines and gullies) constitute 38.5% of the total of crossings on the coastal southern area in the Murcia Region.

Both the average daily traffic intensity and the road category in this type of crossings are lower enough than those observed in crossings drained by bridges and long-span bridges, but higher than those found in *culvert stream-crossings*.

V. CONCLUSIONS

All policy focused on the *fight against flood risk* is based on the prevention. In this type of policy the prevention relative to the road-stream crossings plays an important role. All the measures previously designed and planned in order to reduce or avoid possible damages in such points must go preceded of a suitable knowledge about natural and man-made hazards. Crossing hazard maps should be used for basin planning and land management at local and regional scales. This thematic cartography will be able to serve as a tool of orientation in hydrological, territorial and urban planning. Also it will be a useful instrument for *Emergency* Planning and *Civil Protection,* especially during the alert phase. The diversity of hydrological and geomorphologic hazard situations due to the interference of the *highway infrastructures* at ephemeral *stream crossings* forces to do a detailed analysis of its predictable effects at the different scales usually applied to land use planning. The present work offers a useful methodological approach for developing a specific hazard cartography associated with this type of situations.