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Application of a Channel Stability Assessment Method near Bridges and Culverts: Case Study in Parana State, Brazil

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Abstract: *This study aims to evaluate the level of stability of river channels in bridges and culverts in two watersheds located in the state of Paraná (Brazil), adopting the methodology of the Federal Highway Administration (FHWA). These watersheds are composed by sandstone of the Paraná River Formation in the Parana Watershed 2 (BP2) and by basalt of the Serra Geral Formation in the Paraná Watershed 3 (BP3). The channel stability level was analyzed in 6 structures in the BP2 and 46 structures in the BP3. All structures located on federal, state and municipal asphalted roads were selected. Among the points analyzed in the BP2, 83% were classified in the Good Level category and 17% in the Fair Level category, while in the BP3, 28% were classified in the Excellent level and 72% in the Good level. In both watersheds, bridges and small bridges presented Excellent and Good levels, while in culverts the Good and Fair levels predominated, showing that the first structures created fewer impacts in the fluvial channels than the culverts. These data illustrate the greater instability of the channels in road structures installed in areas where sandstones appear in opposition to structures constructed in areas with basaltic rocks.*

Keywords: *Road Stream Crossing; Channel Stability; Parana Basaltic Plateau; Caiua Sandstone Group; Serra Geral Formation.*

1. INTRODUCTION

The instability of the river channel in a particular stretch may be caused by natural and/or anthropogenic environmental impacts. The construction of bridges and culverts can be considered as an element that introduces changes in the flow dynamics of the canal, affecting erosive and depositional processes that cause ecological impacts (reduction of hydrodynamic and biological connectivity), geomorphological erosion (erosion of the margins and riverbed, upstream bed silting, accumulation of woody debris) and structural (erosion of embankment, erosion of the base of the bridge pillars) [1] [2] [3] [4] [5].

Brazilian researchers point out that the aforementioned impacts can be increased by a combination of factors such as an inadequate design of bridges and culverts [6], extreme rainfall events [7] [8], morphometric characteristics of the drainage basin [9] and occupation of the soil cover in the watershed [10] [11].

Road stream crossings are classified into several types. Bridges are every high work destined to overcome obstacles such as rivers, sea arms and valleys that prevent the physical continuity of a road. If the total length of the device is less than 10 m, the structure is called a small bridge. Culverts are smaller devices installed on first or second order watersheds. These structures are classified according to the form into culverts pipe, when the cross section is circular, and culverts box, when the section represents a square or a rectangle.

The vulnerability of bridges and culverts shows the need to know the instability potential of the river channel around each road stream crossings. For this purpose, field data collection is vital to estimate the stability conditions of the fluvial channels near structures. In this study, the rapid assessment protocol proposed by FHWA (2006) [12] was adopted to estimate the level of river channel stability in adjacent sections of bridges and culverts located in the Paraná Watershed 2 and Paraná Watershed 3 located in the northwestern and western regions of the state of Paraná, Brazil (Figure 1).

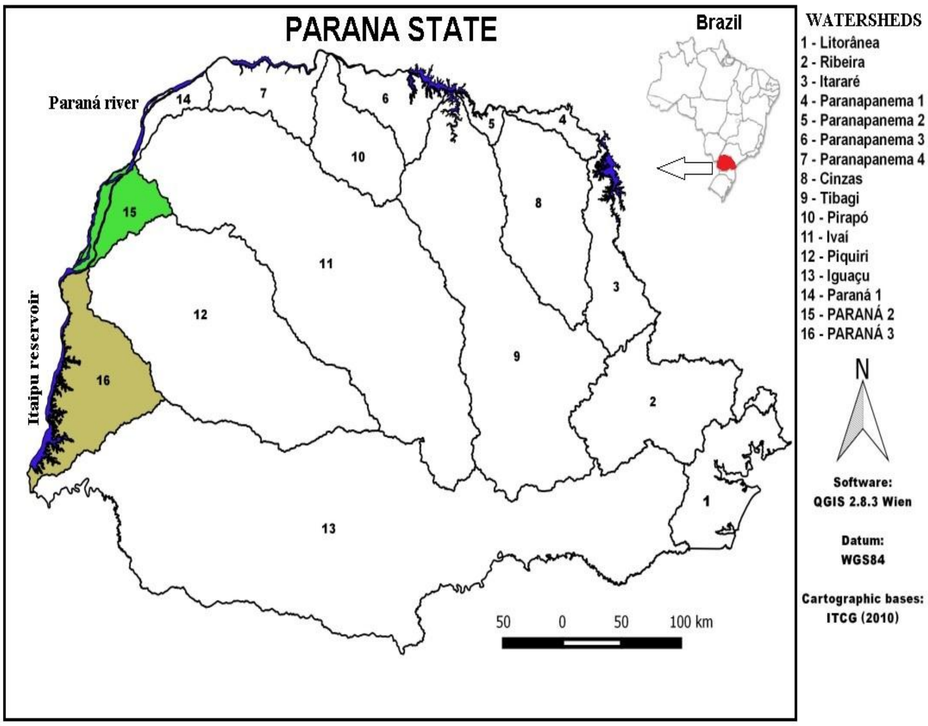

Figure1. *Location of watersheds in study*

2. MATERIALS AND METHOD

2.1. Study Areas

Both watersheds selected in this study are among the 16 watersheds into which the hydrographic network is divided in the state of Paraná. The Paraná watershed 2 is located in the northwest region of Paraná and totals 2,256 km^2*, while the Paraná watershed 3* is located in the western region of the *state and has 7,979 km*^{2}*, representing 1 and 4%, respectively, of the area of the state of Paraná [13].*

The rivers of the Paraná watershed 2 flow into the Paraná River and drain lands of the Paraná River Formation, which is part of the Caiuá Sandstone Group (Upper Cretaceous) of the Paraná Sedimentary Basin. The sands of this Formation were accumulated in a desert environment. They present a reddish-brown to purplish color, fine to medium texture, quartzes, and have a tabular cross stratification [14].

The rivers of the Paraná watershed 3 flow into the Itaipu reservoir, formed by the dam across the course of Paraná. Geologically, this drainage basin is covered by Serra Geral *basalt Formation* (Upper Cretaceous) [15].

In geomorphological terms, both watersheds are inserted in the Cretaceous basaltic plateau (Maack, 1968) [16]. The minimum and maximum altitudes of the Paraná watershed 2 are 228 and 464 m and the Parana watershed 3 are 220 and 760 m. The evolution of the plateau is related to the epirogenetic survey of the South American Platform that occurred from the Upper Cretaceous until the Paleogene-Neogene limit [17], which raised the entire region, subjecting the watersheds to a continuous dissection process.

As for soils, in the Paraná Watershed 2 predominate Latosols and Argisols and in the Paraná Watershed 3 predominate Latosols, Nitosols, Cambisols and Neosols [18]. The climate in both watersheds is Cfa (Classification of Köppen), subtropical mesothermic with hot summers, infrequent frosts, greater rainfall in the summer and no well-defined dry season. The mean annual temperature varies between 20 and 23°C, with an average rainfall between 1,400 and 2,000 mm annually [19].

The original vegetation of the region is the Atlantic Forest [16]**,** which remained untouched until the 1940s, when the replacement of the forest began with permanent crops (coffee) and pastures in the Paraná Watershed 2, and also with temporary crops (corn and soybean) in the Paraná watershed 3 [21].

2.2. Data Collection Method

This study adopts the evaluation protocol proposed by FHWA (2006) [12] to define the level of river channel stability in sections adjacent to bridges, small bridges and culverts. This proposal was applied to 14 physiographic regions of the United States of America, encompassing diverse geological, geomorphological and climatic conditions. This methodology was adopted in this work by the possibility of its application to environments with different morphoclimatic conditions.

The first step in this protocol is an expeditious survey of the watershed and floodplain characteristics, as well as the morphological and sedimentological description of the bed and the margins around the transposition structure, using the form elaborated by FHWA (2006, p. 78-80) [12] from the form originally drafted by Thorne (1998) [22]. The survey execution time varies from 30 to 60 minutes, depending on the type of structure and the ease of access to the river channel.

Bridges, small bridges and culverts selected in this study correspond to structures located on federal, state and municipal asphalted roads that cross both watersheds. The location of watercourse transposition devices was determined by road and hydrographical maps as well as by Google Earth images.

The data collected in the field are used to assign points to thirteen stability indicators according to FHWA (2006, pp. 65-68) [12]: 1) Watershed and flood plain activity and characteristics, 2) Flow habit, 3) Channel pattern, 4) Entrenchment/channel confinement, 5) Riverbed material, 6) Bar development, 7) Obstructions, including rocky outcrops, armor layers, large woody debris jams, grade control, bridge bed silting, revetments, dikes or vanes, riprap, 8) Bank soil texture and coherence, (9) Average bank slope angle, (10) Vegetative or engineered bank protection, (11) Bank cutting, (12) Mass wasting or bank failure and 13) Upstream distance to bridge from a meander impact point and alignment. Each indicator receives a score in the following categories: Excellent (1 to 3 points), Good (4 to 6 points), Fair (7 to 9 points) and Poor (10 to 12 points). The channel stability level is obtained by comparing the total sum of points assigned to all thirteen indicators in each transposition structure with the Montgomery and Buffington channel typologies (1997) [23] as defined in Table 1.

Table1. *Definition of channel stability categories using the channel typologies of the Montgomery and Buffington (1997) [23]*

Channel types: pool-riffle, plane-bed, dune-ripple and engineered channels	
Category	**Ranking**
Excellent	Ranking < 48
Good	49 < Ranking < 84
Fair	85 < Ranking <119
Poor	Ranking >120
Channel types: cascade and step-pool channels	
Category	**Ranking**
Excellent	Ranking < 40
Good	41< Ranking < 69
Fair	70 <Ranking< 98
Poor	Ranking > 98

3. RESULTS AND DISCUSSION

3.1. Parana Watershed 2 (BP2)

The evaluation of the stability conditions of river channels surrounding bridges and culverts in the Paraná Watershed 2 was carried out from October to November 2015. Morphological, sedimentological and land use/occupation data were collected around six structures, of which five are bridges and one is a concrete cellular culvert (Figure 2 and Table 2). The low number of bridges and culverts on the main roads in the Paraná Watershed 2 is due to a basic principle of tracing the roads following water dividers [24], thus reducing the need for bridge construction.

Among the points surveyed, all river sections adjacent to the bridges were classified into the category of Good level of stability, and the channel surrounding the single cell drain was classified into the Fair level category (Table 3). Figure 3 shows two-point photographic records with both Fair and Good stability levels, respectively.

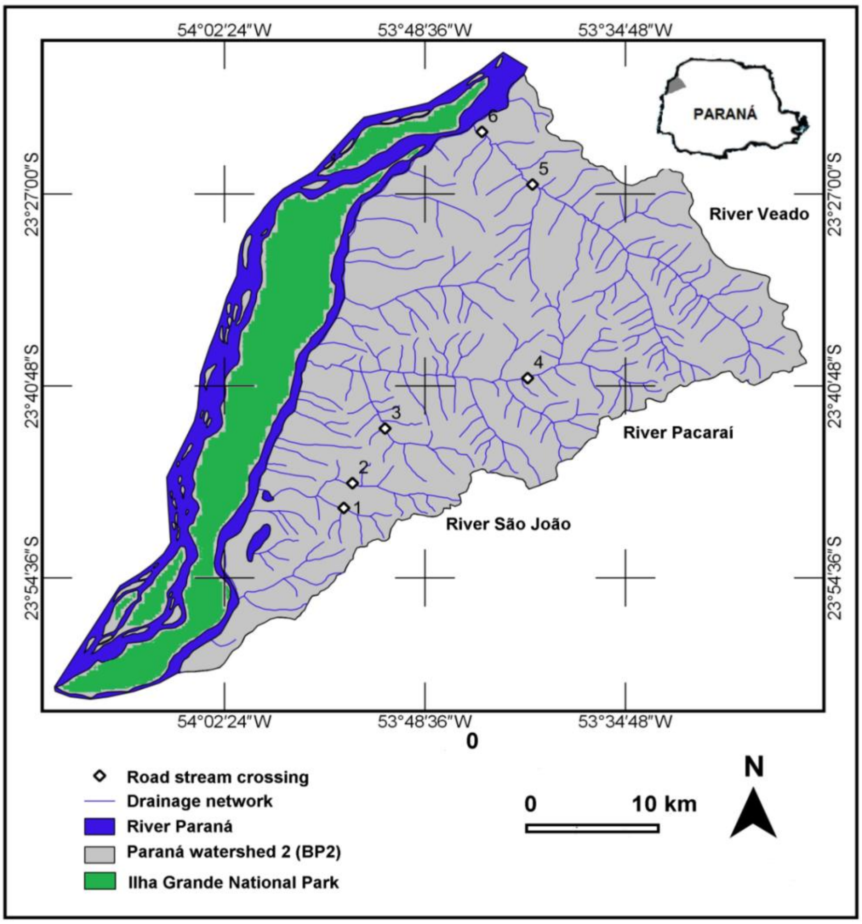

Figure2. *Locations of selected bridges and culverts in Parana Watershed 2*

Table2. *Information on the bridges and culvert box surveyed in the Parana Watershed 2*

Site	Road ID. Municipality	River/ Stream	Geographical coordinates	Altitude (m)	Channel type	Road crossing type
1	PR-490. Altônia	Stream Caju	23^{o} 49’ 34,46” S 53^{o} 54’ 10,94” W	254	Pool-riffle	Culvert Box
2	PR-490. Altônia-São Jorge do Patrocínio	Stream São João	23^{o} 47’ 47,66” S 53^{o} 53’ 35,14” W	257	Pool-riffle	Bridge
3	PR-587. São Jorge do Patrocínio-Nova Esperança	Stream Jequitibá	23^{o} 43’ 51,66” S 53^{o} 51’ 20,63” W	256	Pool-riffle	Bridge
4	PR-485. Pérola-Alto Paraíso	River Pacaraí	23^{o} 40’ 14,38” S 53^{o} 41’ 31,48” W	269	Step-pool	Bridge
5	PR-485. Alto Paraíso-Icaraíma	River Veado	23^{o} 26’ 18,91” S 53^{o} 41’ 11,66” W	252	Plane-bed	Bridge
6	BR-487. Icaraíma	River Veado	23^{o} 22’ 31,87” S 53^{o} 44’ 40,38” W	240	Plane-bed	Bridge

Table3. *Stability assessment based on Table 1.*

Site	Stability indicators													Total	Rating
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**		
1	7	3	8	2	10	3	10	9	9	6	9	3	11	**90**	Fair
2	6	2	5	2	10	6	6	9	9	6	9	6	8	**84**	Good
3	6	2	5	2	12	6	9	7	6	6	7	3	5	**76**	Good
4	6	2	3	2	10	1	5	7	1	2	2	1	8	**50**	Good
5	6	1	2	4	12	3	3	11	2	2	2	1	2	**51**	Good
6	6	1	2	3	12	3	1	11	2	3	2	1	2	**51**	Good

Figure3. *Examples of channel stability in the Parana Watershed 2: A) Site 1, Fair; B) Site 5, Good.*

The sandstones of the Paraná River Formation are prone to the installation and development of erosive features such as ravines and gullies [25]. Ferreira *et al*. (2012) [26] studied this problem by conducting a multi-temporal investigation of the soil loss process between 1963 and 2010 by applying the Universal Loss Soil Equation (USLE) south of the Paraná Watershed 2. The potential erosion resulting from this research presents five classes: very low (VL), low (L), medium (M), high (H) and very high (VH). In 1963, when the forest predominated (74%), the VL class dominated (87%). In 1985, when crops and pastures (96%) dominated land use and classes L and M increased (54.5%). Finally, in 2010, when crops and pastures (76%) still predominated, there was an increase in the forested area (12%), which contributed to the increase of the VL class (52%).

This historical erosion potential of the soils provides us with an idea of the great amount of sediment that has been released into the watercourses, silting the river valleys. With respect to this process, Ferreira *et al*. (2012) [26] commented on a reduction of river depth and width in 2010 compared to the situation of these rivers in the early 1980s, when a greater depth of the rivers provided conditions for leisure practices.

The silting of watercourses is most evident in the rivers located in the southern part of the Paraná Watershed 2, where the terrain presents a weak dissection, with wide valleys and well-developed alluvial plains, giving rise to meandering traces (see Figure 3A). This situation leads to high levels of instability, as in the case of Structure 1 (culvert), which sums 89 points (Fair Level). Structures 2 and 3 are classified in the Good level, with 84 and 76 points, respectively, very close to the Fair level, which starts at 85 points. In these three structures, high values of the indicators such as slope of the margin phase, riparian forest width and evidence of marginal erosion are responsible for the high score.

The other points (4-6) are located in the central and northern parts of the Paraná Watershed 2, which show a relief with a medium dissection, a more rectilinear channel trajectory and outcrops of the Paraná River Formation in channel beds, which have a low degree of entrenchment (see Figure 3B). These conditions provide Good stability indexes, with scores around 50 points (Table 3), already close to the Excellent level, whose score is equal to or less than 48 points.

Despite the low number of structures surveyed in the Paraná Watershed 2, it was possible to observe the predominance of indexes indicating a low stability, which may be related to the presence of sandstone-derived soils, which are more prone to erosion.

3.2. Parana Watershed 3 (BP3)

The evaluation of river channel stability conditions was carried out between 2011 and 2012 around 46 watercourse transposition devices grouped in 18 bridges, 6 small bridges, 15 culverts pipe and 7 culverts box (Figure 4 and Table 4).

Among the 46 devices surveyed, 33 were classified in the Good stability level and 13 in the Excellent level (Table 5). Some examples of devices with respective stability levels are shown in Figure 5. It should be noted that there was no record of any structure with Fair or Poor channel stability levels.

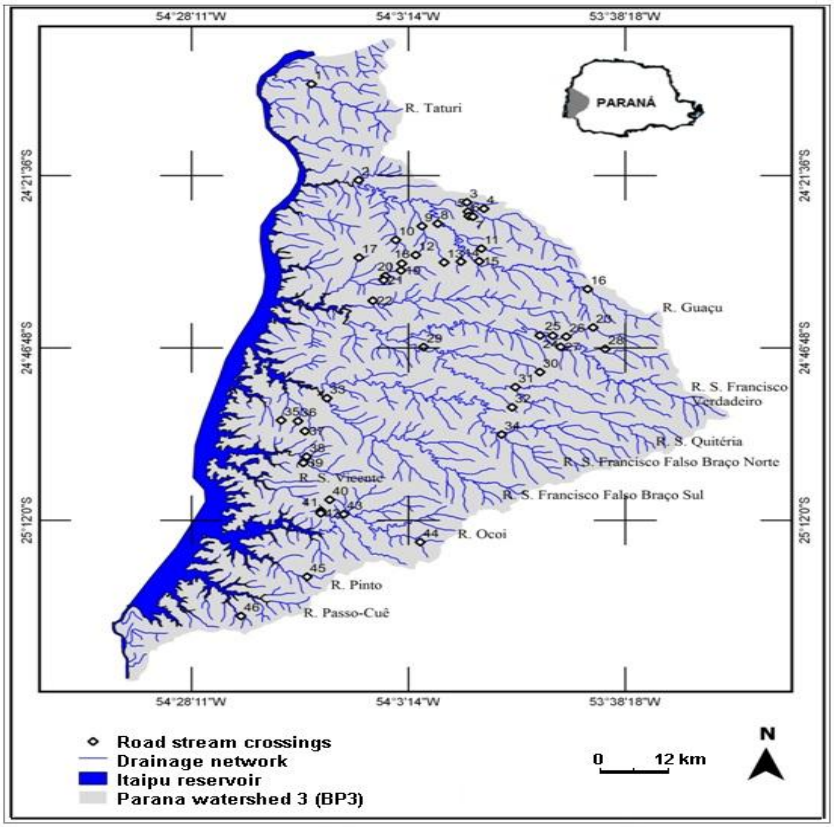

Figure4. *Locations of selected bridges and culverts in the Parana Watershed 3*

Table4. *Information on the bridges, small bridges and culvert box and culvert pipes surveyed in the Parana Watershed 3*

Site	Road ID. Municipality	River/stream	Geographical Coordenates	Channel type	Road crossing types
1	BR 163. Guaíra	River Taturi	24°08’13”S 54°14’24”O	Plane-bed	Bridge
2	BR 163. Terra Roxa/Mercedes	River Guaçu	24°22’16”S 54°08’58”O	Plane-bed	Bridge
3	Municipal road. Nova Santa Rosa	River Jaguarandi	24°25’31”S 53°56’31”O	Plane-bed	Bridge
4	PR 491. Nova Santa Rosa	Stream Antas	24°26’27”S 53°54’33”O	Pool-riffle	Small bridge
5	Municipal road. Nova Santa Rosa / Maripá	Stream Colibri	24°26’53”S 53°56’23”O	Plane-bed	Culvert pipe
6	PR 491. Nova Santa Rosa	Stream Xerê	24°27’32”S 53°56’17”O	Plane-bed	Small bridge
7	PR 491. Nova Santa Rosa	Stream Jaguarandi	24°27’37”S 53°55’49”O	Plane-bed	Bridge
8	PR 491. Nova Santa Rosa/Marechal C. Rondon	Rio Guaçu	24°28’38”S 53°59’52”O	Plane-bed	Bridge
9	PR 491. Marechal C. Rondon	River Quatro Pontes	24°29’00”S 54°01’41”O	Plane-bed	Small bridge
10	BR 163. Marechal C. Rondon	Stream Guavirá	24°31’01”S 54°04’42”O	Pool-riffle	Culvert Box
11	PR 589. Toledo	Stream Gavião	24°32’17”S 53°54’51”O	Pool-riffle	Culvert pipe
12	BR 163. Marechal C. Rondon	Stream Guará	24°33’13”S 54°02’24”O	Step-pool	Culvert Box
13	BR 163. Quatro Pontes	River Quatro Pontes	24°34’18”S 53°59’08”O	Plane-bed	Culvert pipe
14	PR 239. Quatro Pontes	Stream Leão	24°34’11”S	Plane-bed	Culvert pipe

			53°57’12”O		
15	PR 239. Quatro Pontes/Toledo	River Guaçu	24°34’08”S 53°55’06”O	Plane-bed	Bridge
16	PR 182. Toledo/Palotina	River Guaçu	24°38’12”S 53°42’38”O	Plane-bed	Culvert Box
17	PR 467. Marechal C. Rondon	Stream Curvado	24°33’36”S 54°08’56”O	Pool-riffle	Culvert Box
18	Municipal road. Marechal C. Rondon	Stream Borboleta	24°34’28”S 54°04’00”O	Step-pool	Culvert Box
19	Municipal road. Marechal C. Rondon	River Arroio Fundo	24°35’29”S 54°04’06”O	Pool-riffle	Small bridge
20	Municipal road. Marechal C. Rondon	Stream Palmital	24°36’19”S 54°05’54”O	Plane-bed	Small bridge
21	Municipal road Marechal C. Rondon	Stream Mirim	24°36’53”S 54°06’05”O	Pool-riffle	Culvert Box
22	Municipal road. Marechal C. Rondon	River Marreco	24°39’54”S 54°07’20”O	Pool-riffle	Bridge
23	BR 467. Toledo	River Toledo	24°43’49”S 53°42’00”O	Step-pool	Bridge
24	PR 317. Toledo	Stream Lajeado	24°44’59”S 53°48’07”O	Pool-riffle	Culvert Box
25	PR 317. Toledo	River São Francisco Verdadeiro	24°45’01”S 53°46’38”O	Plane-bed	Bridge
26	Municipal Road. Toledo	River Toledo	24°45’09”S 53°45’05”O	Plane-bed	Bridge
27	PR 585. Toledo	River São Francisco Verdadeiro	24°46’39”S 53°45’44”O	Plane-bed	Bridge
28	BR 467. Toledo/Cascavel	River Lopeí	24°46’57”S 53°40’36”O	Plane-bed	Bridge
29	PR 317. Ouro Verde do Oeste/São José das Palmeiras	River Santa Quitéria	24°46’41”S 54°01’30”O	Bedrock	Bridge
30	PR 585. Toledo	River Ouro	24°50’20”S 53°48’07”O	Step-pool	Culvert Box
31	PR 585. Toledo/São Pedro do Iguaçu	River Santa Quitéria	24°52’32”S 53°50’56”O	Step-pool	Bridge
32	PR 585. São Pedro do Iguaçu	Stream São Pedro	24°55’29”S 53°51’19”O	Pool-riffle	Culvert Box
33	PR 488. Santa Helena	River São F. Falso Braço Sul	24°54’09”S 54°12’37”O	Plane-bed	Bridge
34	PR 585. São Pedro do Iguaçu/Vera Cruz do Oeste	River Turvo	24°59’28”S 53°52’31”O	Step-pool	Bridge
35	PR 495. Santa Helena	Stream Pacuri	24°57’23”S 54°17’53”O	Plane-bed	Culvert Box
36	PR 495. Santa Helena	River Moreninha	24°57’30”S 54°15’57”O	Plane-bed	Culvert Box
37	PR 495. Santa Helena	River Morenão	24°58’58”S 54°15’08”O	Plane-bed	Culvert pipe
38	PR 495. Missal	Stream Lajeadinho	25°02’42”S 54°14’58”O	Plane-bed	Culvert Box
39	PR 495. Missal	River São Vicente	25°03’36”S 54°15’20”O	Plane-bed	Bridge
40	PR 495. Missal	River São João	25°09’00”S 54°12’18”O	Pool-riffle	Culvert Box
41	PR 497. Itaipulândia	Stream Cedro	25°10’38”S 54°13’19”O	Pool-riffle	Culvert pipe
42	PR 497. Itaipulândia	Stream Cedro	25°10’58”S 54°13’20”O	Plane-bed	Culvert pipe
43	PR 495. Missal/Medianeira	River Ocoí	25°11’07”S 54°10’40”O	Plane-bed	Bridge
44	BR 277. Medianeira	River Ocoí	25°15’11”S	Pool-	Small bridge

			54°01’53”O	riffle	
45	PR 497. São Miguel do Iguaçu	River Leão	25°20’16”S 54°14’54”O	Pool-riffle	Culvert Box
46	BR 277. Santa Terezinha de Itaipu	Stream Bonito	25°26’00”S 54°22’30”O	Step-pool	Culvert Box

Table5. *Stability assessment based on Table 1.*

Site	Stability indicator													Total	Rating
	1	2	3	4	5	6	7	8	9	10	11	12	13		
1	5	1	1	5	10	1	10	6	12	6	2	1	1	**62**	Good
2	5	1	1	5	5	1	3	4	10	6	3	1	1	**46**	Excellent
3	5	1	3	2	2	1	3	2	12	6	3	1	3	**44**	Excellent
4	5	3	5	2	2	1	3	2	12	6	3	1	10	**55**	Good
5	5	3	1	2	2	1	4	2	12	9	3	1	1	**46**	Good
6	5	3	1	2	2	1	6	2	12	6	3	1	1	**45**	Excellent
7	5	1	1	2	2	1	3	2	12	6	3	1	1	**40**	Excellent
8	5	1	1	2	5	1	3	4	10	6	3	1	1	**43**	Excellent
9	5	2	1	2	2	1	3	2	12	9	3	1	1	**44**	Excellent
10	7	3	1	3	8	1	9	6	12	9	6	1	1	**67**	Good
11	5	3	2	2	2	1	6	2	12	6	4	1	5	**51**	Good
12	8	3	1	3	2	1	6	2	12	7	3	1	1	**50**	Good
13	7	3	1	4	2	1	6	2	12	8	3	1	1	**51**	Good
14	5	2	1	2	5	1	6	4	12	7	3	1	1	**50**	Good
15	5	1	1	2	5	1	3	4	12	6	7	1	1	**49**	Good
16	5	1	3	7	5	1	9	2	12	6	6	1	12	**70**	Good
17	5	3	2	2	2	1	6	2	12	6	4	1	3	**49**	Good
18	7	3	1	9	1	1	7	1	12	6	1	1	1	**51**	Good
19	7	3	1	3	1	1	3	1	12	8	3	1	1	**45**	Excellent
20	5	3	3	2	1	1	6	2	12	7	6	1	6	**55**	Good
21	5	3	3	2	1	1	6	2	12	7	6	1	6	**55**	Good
22	5	1	1	5	3	1	3	3	12	7	3	1	1	**46**	Excellent
23	8	2	1	7	2	1	3	2	10	9	3	1	1	**50**	Good
24	5	2	1	2	3	1	9	2	12	6	6	1	3	**53**	Good
25	9	1	1	2	5	1	3	2	12	6	3	1	1	**47**	Excellent
26	9	2	1	2	3	1	3	2	12	6	3	1	3	**48**	Excellent
27	9	1	1	2	4	1	3	3	12	8	3	1	1	**49**	Good
28	5	1	1	1	5	1	3	2	12	6	5	1	10	**53**	Good
29	5	1	1	7	5	1	3	2	12	6	3	1	1	**48**	Good
30	5	3	1	3	3	1	6	2	12	6	3	1	1	**47**	Good
31	5	1	1	7	4	1	3	3	12	7	3	1	3	**51**	Good
32	7	3	1	2	3	1	6	2	12	6	3	1	2	**49**	Good
33	5	1	1	7	5	1	3	2	12	6	3	1	1	**48**	Excellent
34	5	1	1	3	4	1	3	2	12	7	3	1	1	**44**	Good
35	6	3	1	2	2	1	4	2	12	11	3	1	2	**50**	Good
36	7	3	1	7	2	1	6	2	12	11	3	1	2	**58**	Good
37	5	3	1	2	2	1	8	2	12	11	3	1	2	**53**	Good
38	5	3	1	2	3	1	6	2	12	6	3	1	1	**46**	Excellent
39	5	1	1	2	2	1	3	2	12	6	3	1	1	**40**	Excellent
40	5	3	2	2	1	1	6	2	12	8	3	1	8	**54**	Good
41	6	3	2	2	1	1	9	2	12	8	5	1	8	**60**	Good
42	5	3	2	2	1	1	7	2	12	8	5	1	8	**57**	Good
43	6	1	1	7	4	1	3	3	12	11	3	1	1	**54**	Good
44	5	2	1	7	3	1	4	2	12	6	3	1	3	**50**	Good
45	9	3	3	4	2	1	12	2	12	9	6	1	3	**67**	Good
46	5	3	3	4	2	1	10	2	12	6	3	1	7	**59**	Good

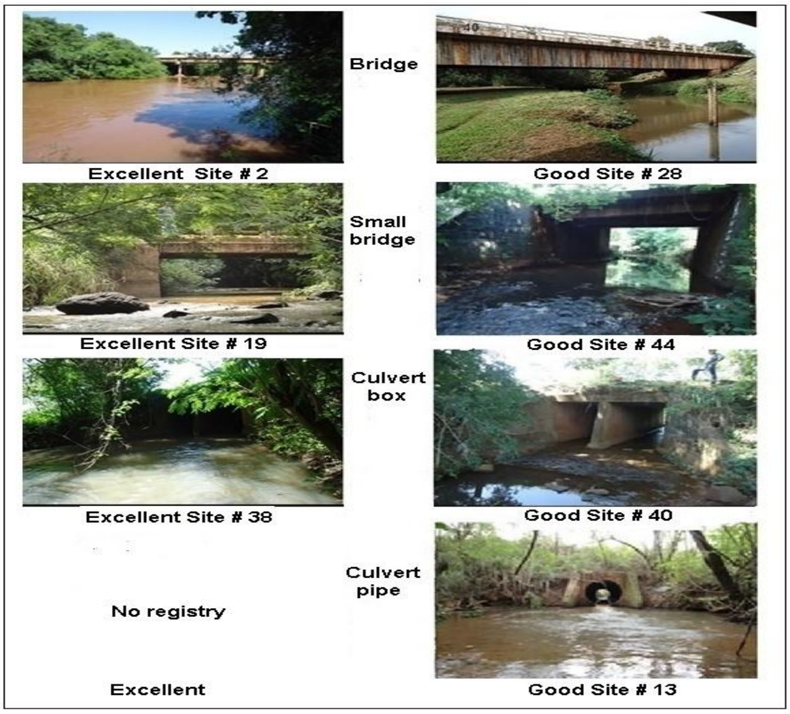

Figure5. *Examples of channel stability in the Parana Watershed 3*

Next, the influence of the types of devices, the rocky substratum and the pedological cover on the levels of river channel stability in the Paraná Watershed 3 is analyzed.

The ecological and morphological impacts resulting from the installation of watercourse transposition devices are greater in culverts than in bridges and small bridges. Due to this problem, states and the prefectures in Canada and the United States of America promoted the substitution of culverts for small bridges [27]. Because of the larger area of the central span of the bridges and small bridges, the flow pattern during flooding undergoes little modification and causes less erosion or silting. In culverts, the situation is reversed: the smaller cross-sectional area leads to a partial damming of the stream during floods, generating extravasation of the stream over the culvert, destruction of the landfill, accumulation of woody debris and intensification of marginal erosion. Due to this dynamics, the number of bridges and small bridges with Excellent and Good levels is equal, while in culverts, the Good levels of stability are predominantly above the Excellent levels (Figure 6).

The morphological and ecological impacts upstream and downstream of culverts pipe are greater than in culverts box [28]. In this study, this conclusion is corroborated by the lack of excellent levels in the culverts pipe surveyed (Figure 6), and by the finding that the devices with lower stability indexes are culverts pipe such as devices number 10, 16 and 45 (see Tables 4 and 5), which add up to 67, 70 and 67 points, respectively. It should be remembered that the Good level for channels with threshold-depression, flatbed and dunes ranges from 49 points (greater stability) to 84 points (lower stability) (Table 5).

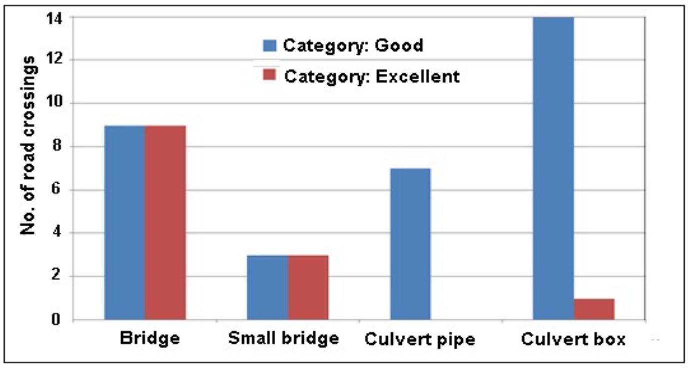

Figure6. *Comparison between the stability categories of fluvial channels and types of road crossings in the Parana Watershed 3.*

The rivers of the Paraná Watershed 3 are plateau water courses with generally carved channels alternating alluvial and rocky segments, with predominance of bed typologies associated with accentuated slopes such as flat bed, threshold-depression and rocky beds. The predominance of the flat bed typology, present in 25 of 46 high structures, as well as the gradient-depression and rocky bed typologies (Table 4), indicate highly energetic fluvial environments, which can cause conditions of instability in the channels. However, this situation does not materialize due to the basaltic substrate outcropping in the riverbed and the low erodibility of soils that occupy lower slopes and valley bottoms (Nitosols, Cambisols and Neosols). These soils present a greater resistance to water erosion [29], which is why they are less likely to suffer from landslides and gullies [30]. These geological and pedological characteristics of the Paraná Watershed 3 may be fundamental to explain the predominance of the levels of stability Good and Excellent and the absence of Fair and Poor levels.

4. CONCLUSIONS

The data collected on the bridges and culverts in the Paraná Watershed 2, dominated by residual sandstone soils (Paraná River Formation), were classified as Good and Fair, with an average value of 67.2 points. On the other hand, in the Paraná Watershed 3, constituted by residual basalt soils (Serra Geral Formation), which is more resistant to erosion, the average value of the stability levels was 51.1 points, with a predominance of Good and Excellent levels. This comparison illustrates the greater vulnerability of road structures in areas where sandstones emerge than in regions covered by basaltic rocks**.**

In this work, the FHWA protocol (2006) [12] was applied in its entirety, without any changes in both stability indicators and the respective scores, as well as in the Montgomery and Buffington (1997) classification [23]. The data collected may serve as basis for the organization of a database that should be complemented with the data collection in watercourse transposition devices located on unpaved back roads. These data may support further detailed studies on the erosive-depositional framework of the channels. The stability of river channels around road works is a current problem that may worsen with the increased risk of floods caused by climate change.

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