

## IMPROVEMENT OF TSIMIRORO HEAVY OIL UTILIZATION IN THE ROAD SECTOR

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### Abstract

The Tsimiroro heavy oil has strong economic potential for Madagascar. Road construction is among the key sectors. The objective of this study is to enhance the performance of roads made with this product. The methodology involved understanding the physicochemical properties of the heavy oil through hydrocarbon characterization and analysis of bitumen attributes. Subsequently, the removal of light cuts through thermal treatment is applied to the heavy oil before developing multiple formulas that will undergo Marshall and Duriez tests. The results obtained show some similarities with previous research, except for the following key points: - the water content is below 0.05%, compared to 10% to 16% in 2011; - heat loss ranges from 5.6% to 10.4%, significantly lower than the 34.6% recorded in 2016. These improvements contribute significantly to reducing the time and energy required during processing. The stability during Marshall tests is 1,620 daN, which is 1.88 times more stable compared to previous results. The Duriez tests demonstrate a stability ratio of 1.43 at 18°C and 0.60 at 0-5°C, indicating that the product can withstand heavy traffic. There is a significant improvement in the geotechnical properties of the heavy oil in cold mix asphalt. The absence of dope and additives makes the use of heavy oil even more cost-effective, resulting in a 35% savings per kilometer compared to bitumen. This study proposes the implementation of a test section under high traffic conditions.

**Keywords:** Cold mix asphalt, Bitumen, Heat treatment, Binder, Madagascar.

## 1- Introduction

Madagascar rich in potholes and impracticable roads, Madagascar poor in exploiting its underground oil resources. In 2020, a study conducted by the Economic Development Board of Madagascar revealed that the 'Red Island' is composed of 49,250 kilometers of roads and tracks[1]. According to Madamag, « Based on the latest statistics on the road network in Madagascar, 64% of the country's roads are in very poor condition due to lack of maintenance and upkeep, as well as natural disasters»[2]. EDBM even mentions that only 11% of the roads are in good condition [1]. Less than 20% of the 30,000 kilometers of roads in Madagascar were paved in 2020 [2].

Bitumen stands as the primary binder used in road construction. Madagascar abounds in several categories of hydrocarbons, including the heavy oil of Tsimiroro. In 2011, a study conducted by RAKOTOARISON Pierre Donat demonstrated that the Tsimiroro heavy oil could serve as a substitute for imported pure bitumen. [3]. The test panels conducted in rural areas demonstrated that the product, when applied as cold mix asphalt, exhibited suitable characteristics for low traffic conditions, with a stability of 860 daN.

The present study focuses on the application under heavy traffic conditions, resulting in a Marshall stability exceeding 1,000 daN. Consequently, research into binder optimization, including its thermal treatment, was undertaken. Furthermore, our aim is to provide a solution with a cost per kilometer and a carbon footprint more appealing than the use of traditional bitumen. The significant reduction in additive usage while enhancing rheological properties stands as a decisive factor. The vision is to employ the product for the maintenance of urban roads.

## 2- Methods

### The heavy oil from Madagascar

The study primarily focused on the heavy oil extracted from Tsimiroro's Block 3104, located on the west coast of Madagascar. This site is positioned at 18° 21' 08" South latitude and 45° 00' 17" East longitude, covering an area of 6,670 km<sup>2</sup> and holding an estimated 1.7 billion barrels of heavy oil, with 1.1 billion barrels deemed exploitable (Figure 1). The heavy oil is found at depths ranging from 40 to 300 meters and is extracted using a steam injection method [4], [5]. Notably, heavy oil differs from conventional petroleum in terms of its viscosity and density [6]–[8]. This research employed a simple random sampling approach.

### Physico-chemical characterization of Tsimiroro heavy oil at OMNIS

An initial study phase was conducted at the Laboratory Directorate of Office des Mines Nationales et Industries Stratégiques. Parameters such as density measured by a pycnometer, viscosity, water and sediment content determined through centrifugation, as well as the closed-cup flash point and ignition point of heavy oil, were examined.

The **specific gravity** of heavy oil is defined in relation to water. A 25 mL glass capillary stoppered pycnometer is employed to conduct the procedure following the protocol outlined in ISO 3838-2004. As a petroleum product, the density of heavy oil is expressed in "API gravity" using the formula F1 provided in ISO 3838-2004.

$$\text{API} = \frac{141.5}{\text{Specific gravity at } 15^{\circ}\text{C}} - 131.5 \quad F1$$

The **kinematic viscosity** was acquired through the measurement of the gravity flow time "t" of a volume of heavy oil between two marked points on a capillary viscometer at a temperature of 50°C. The protocol adhered to the guidelines set forth by ISO 3104-1994. The viscosity "v" in cSt is calculated using formula F2:

$$V = \frac{(C1 \times t1) + (C2 \times t2)}{2} \quad F2$$

With C1 : lower bulb calibration constant ;  
t1 : liquid flow time in the lower bulb in seconds ;  
C2 : upper bulb calibration constant ;  
t2 : liquid flow time in upper bulb in seconds.

The **Basic Sediment and Water** analysis provided the percentage of water and sediment content following the centrifugation of the sample. The procedural standard adhered to was ISO 3734-1997. The volume was determined through visual reading and subsequently expressed according to the formula F3:

$$\text{BSW} = \frac{S}{V} * 100 \quad F3$$

With S : volume of water and sediment after centrifugation ;  
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V : volume of sample.

**Flash point** and **ignition point** were determined using a Pensky-Martens closed-cup flash point apparatus. The protocol followed the guidelines outlined in ISO 2719-2016.

### **Physico-chemical characterization of Tsimiroro heavy oil according to bitumen chemical properties**

The second phase of characterization was conducted at the Laboratoire National des Travaux Publics et du Bâtiment in the Materials Department. Among the characterizations performed were passive adhesion, needle penetration and heat loss assessments.

The **passive adhesion** test conducted adhered to the NF EN 13614 standard. This test assesses the binding capacity with aggregates under the influence of water at 60°C for 14 hours. For the experiment, we utilized [10-14] grade limestone.

The **needle penetration** test determined the consistency of heavy oil at intermediate service temperatures. It was conducted following the French standard EN 1426. The handling temperature was maintained at 25°C.

**Heat loss** analysis determined mass losses during the heating of bituminous products at 163°C for 5 hours. The procedure is governed by the NF T66 01 standard. Heat loss is expressed as a percentage according to the formula F4 :

$$\text{Percentage heat loss} = \frac{P2-P3}{P2-P1} * 100 \quad F4$$

With P1 : empty cup mass ;  
P2 : total mass (cup + heavy oil) before heating;  
P3 : total mass (cup + heavy oil) after heating.

### **Laboratory test on the application of heavy oil as a road surfacing binder**

The third phase of the studies continued at the Laboratoire National des Travaux Publics et du Bâtiment, still within the Materials Department. Prior to conducting the Marshall and Duriez tests, aggregate identification was carried out, not forgetting the treatment of heavy oil to enhance its characteristics. Throughout the experiments, limestone was consistently used as the aggregate material.

The **aggregate identification through granulometry** serves to identify its granular class and the dimensional distribution of grains. The sampling was obtained through random cluster sampling. The protocol implemented is governed by the P 18-560 standard.

The **enhancement of the heavy oil** was achieved through a **thermal treatment**. The temperature was raised to reduce the presence of light products, such as short-chain carbon

compounds. The removal of these components results in improved rheological properties of the heavy oil.

The **Marshall test** determined the mechanical characteristics of a bituminous mixture, including Marshall stability and flow. The NF P98-251-2 standard was implemented for conducting these tests. Twenty-seven formulations were tested before achieving the set objectives in the Marshall tests. Variations in binder percentage, additives, and binder type were introduced during the experimentation process.

The **Duriez test** is employed to determine, at a specific temperature and compaction level, the water resistance of a hydrocarbon mixture based on the ratio of compressive strengths with and without immersing the test specimens. The test temperatures were set at 18°C and 0-5°C. The procedure is governed by the NF P98-250-1 standard. The stability ratio is calculated according to the formula F5 :

$$\text{Stability ratio} = \frac{R'c}{Rc} \quad F5$$

With R'c : Resistance after 7-day immersion ;  
Rc : Resistance after 7 days exposed to air.

### 3- Results

The various results obtained during the study stem from multiple tests, serving to both validate the accuracy of the investigations and establish an average value.

#### **Physico-chemical characterization of Tsimiroro heavy oil at OMNIS**

The initial characterization of the physicochemical properties of the heavy oil conducted within the OMNIS laboratory yielded the results listed in the Table 1.

The density of the heavy oil exhibited an average of 0.97. The median was also 0.97. The results displayed zero variance and a standard deviation of 0.01. Therefore, the mean was adopted to represent the API gravity using formula F1, resulting in a density of 12.81° API.

The kinematic viscosity at 50°C, after calculation using formula F2, exhibited an average of 2,847.76 cSt. The results showed a variance of 0.04 and a standard deviation of 0.20. The passage time through the lower bulb was 341s and 344s, while the passage time through the upper bulb was 449s for both.

After calculation using formula F3, the water and sediment content yielded results all below 0.05%. This was the significantly lower graduation. Therefore, both variance and standard deviation were zero.

During the tests, the flash point provided a consistent temperature of 132°C. The ignition point also exhibited the same temperature of 135°C. Both the mean and mode were therefore directly determined. Variance and standard deviation were both zero.

#### **Physico-chemical characterization of Tsimiroro heavy oil according to bitumen chemical properties**

The analysis results obtained during the heavy oil characterization within the Material Department of LNTPB are listed in Table 2.

The passive adhesion test consistently yielded results where less than 50% of the aggregates were coated with crude heavy oil. Due to the approximate nature of result readings. As a result, variance and standard deviation could not be calculated.

Penetration could not be measured as the needle directly reached the bottom of the container with each penetration under the required conditions.

After calculation using formula F4, the heat loss presented an average result of 10.38%. The variance among the experiments was 0.13, with a standard deviation of 0.36.

### **Laboratory test on the application of heavy oil as a road surfacing binder**

Figure 2 compiled the results of the particle size analysis of limestone aggregates in the [0-4], [4-6], and [6-10] size classes.

The thermal treatment of a 500g sample of heavy oil resulted in a loss of 5.6%.

Table 3 contained the detailed results and parameters for each formulation. The optimal formulation resulted in an average stability of 1620 daN, with a variance of 1600 and a standard deviation of 40. The average flow of the best formulation was 3.15 mm, showing a variance of 0.12 and a standard deviation of 0.35. The minimum stability observed during a cold crush was 650 daN for Formula 5, while the maximum stability recorded during a cold crush reached 2400 daN. Table 4 presented a comparison between the obtained results and previous findings, aligning them with the required standards.

For the Duriez tests at 18°C, the stability after 7 days in the air averaged 405 daN, with a variance of 2025 and a standard deviation of 45. After immersion in water, the stability averaged 580 daN, with a variance of 400 and a standard deviation of 20. The stability ratio at 18°C was 1.43. For tests at 0-5°C, the average stability after 7 days in the air was 1300 daN, with a variance of 97,408 and a standard deviation of 311.93. For tests immersed in water, the average stability was 780 daN, with a variance of 6,400 and a standard deviation of 80.

#### 4- Discussion

##### **Physico-chemical characterization of Tsimiroro heavy oil at OMNIS**

Les résultats de la caractérisation de la densité, la viscosité, le point d'éclair et le point d'inflammation de l'huile lourde sont similaires par rapport à l'étude en 2011[3].

The analysis of water and sediment content confirms the negligible impurity levels in the heavy oil. In comparison, previous studies conducted in the same laboratory reported a content of 0.7% [9]. Whereas in 2011, it was in the range of 10 to 16% [3]. This improvement could be attributed to advancements in extraction techniques and possibly to settling in the tank.

##### **Physico-chemical characterization of Tsimiroro heavy oil based on bitumen chemical properties**

Passive adhesiveness below 50%, not meeting the standard of over 90%, aligns with similar outcomes from previous studies [3], [10]. This resemblance is attributed to the presence of light, short-chain carbon products, leading to a stripping phenomenon.

The needle penetration of crude heavy oil yields the same result as in previous studies, being non-measurable [3], [10]. The reason is that the substance is in a liquid state, unlike bitumen, which is the basis for the classification.

The reduced heat loss of 10.38% indicates a significant improvement compared to previous results of 37% in 2011 [3] and 35% in 2016 [10] for the crude heavy oil from Tsimiroro. This suggests a considerable decrease in the percentage of pumping solvent and water during the extraction process.

##### **Laboratory Test of Heavy Oil Application as a Road Coating Binder**

Following the particle size analysis, the asphalt mixture formulation is developed. Hence, the following composition is defined: 45% of sand [0-4]; 30% [4-6]; and 25% [6-10].

During the thermal treatment of heavy oil, the heat loss obtained is significantly lower (5.6%) compared to that during the identification of physico-chemical properties of the oil (10.38%). This disparity is explained by the exposure of the sample in the beaker despite its mass of 500 g. Therefore, it was necessary to mix the heavy oil during the thermal treatment to homogenize the sample.

During the Marshall tests, several parameters were varied to obtain the best formulation, including the binder percentage, the type of binder (crude heavy oil, treated heavy oil), and the use of additives (dolomite, cement). Table 3 summarizes all the Marshall test results along with the key characteristics.

Several of the conducted tests meet the required standards and show potential (samples 13-16-18-19-20-21-23-24-25). Considering a better cost-effectiveness ratio for on-site implementation, **tests 13-16-23 are the preferred compositions, also showing a significant improvement in stability compared to previous studies** (refer to Table 4). The use as a cold mix asphalt is therefore the parameter through which we have achieved advancement. As a hot mix asphalt, further intensive treatment of the heavy oil is necessary, along with the addition of polymers [10].

The obtained stability ratio complies with the required standard for cold asphalt mixtures (higher than 0.7). It even demonstrates good compatibility with water at 18°C, hence the result exceeding 1. This indicates that in contact with water, the asphalt exhibits less degradation. The heavy oil is therefore quite stable in the presence of water. Referring to the previous study, the obtained result marks an evolution in understanding the good water resistance [3]. It was observed that the bath in which the specimen is placed contains fine clay particles, and it is possible that they played a role in the behavior of the specimen.

The stability ratio obtained after the Duriez test at 0-5°C indicates that the asphalt mixture exhibits high stability compared to a processing temperature of 18°C. However, water resistance is lower. This could suggest the possibility of a reaction with the fine clay particles, especially considering their absence in the immersion container of the refrigerator.

Table 6 presents the detailed calculations indicating that the use of heavy oil as a binder is 46.25% cheaper than bitumen. We took the minimum binder percentage for bitumen and the optimal percentage discovered during the research for heavy oil. The cost per kilometer for heavy oil is \$43,000. For bitumen, the cost per kilometer is \$80,000 for the same road surface to be constructed. Considering the expenses for thermal treatments, **heavy oil is thus 35% less expensive than bitumen.**

## 5- Conclusion

The heavy oil from Tsimiroro was the key focus of the research. Its density, kinematic viscosity, flash point, ignition point, water and sediment content, and thin-layer chromatographic analysis were conducted in the OMNIS laboratory. Following this, the characterization of its passive adhesiveness, needle penetration, heat loss, and overall adhesiveness was carried out in the LNTPB laboratory. The improvement of the heavy oil was achieved through thermal treatment at less than 250°C. Once treated, the formulation of the best composition is compared against the Marshall and Duriez tests.

The primary focus of the research is to enhance the performance of cold mix asphalt using heavy oil as a binder. Additionally, the goal was to achieve a stability exceeding 1,000 daN, allowing the asphalt to withstand heavier traffic than before. The current research demonstrates a significant improvement in stability during the Marshall tests, reaching 1,620 daN, which is a 1.88-fold improvement compared to previous results. The rutting in the tests complies with standards. The stability ratio from the Duriez test at 18°C is 1.43. The use of this heavy oil instead of imported pure bitumen provides a minimum 35% cost saving per kilometer and a substantial reduction in carbon footprint. The study thus opens the possibility of using heavy oil as a binder for cold mix asphalt in the face of heavier traffic.

However, to date, the study has met the laboratory requirements. Our aim is now to apply the findings to real traffic and actual field conditions. Procedures are underway to assist the country in paving a path toward development.

## 6- Acknowledgements

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## 8- Tables

*Table 1: Physico-chemical characteristics of Tsimiroro heavy oil (OMNIS laboratory analysis)*

<b>Characteristics</b>	<b>Results of current analyses</b>	<b>Results of previous studies [3]</b>
Density per pycnometer	12.81 API	
Kinematic viscosity at 50°C	2,847.76 cSt	
<b>Water and sediment content</b>	<b>&lt; 0.05%</b>	<b>10 to 16%</b>
Flash point	132°C	
Ignition point	135°C	

Table 1 depicts the various outcomes acquired during the physicochemical characterizations of Tsimiroro heavy oil within the OMNIS laboratory. The values present the statistically significant average of the experiments. It also showcases the findings from previous studies, thereby enabling a comprehensive comparison.

*Table 2 : Results of physico-chemical characterizations of heavy oil according to bitumen chemical properties*

<b>Characteristics</b>	<b>Results of current analyses</b>	<b>Results of previous analyses[3]</b>	<b>Standards</b>
Passive adhesion	Less than 50% (Crude heavy oil / limestone)	Poor (Any rock)	Higher than 90%
Needle penetration	Not measurable (Crude heavy oil)	95 (Treated heavy oil residue)	
<b>Heat loss</b>	<b>10,38%</b>	<b>37%</b>	

Table 2 illustrates the diverse findings obtained during the physicochemical characterizations of heavy oil based on the chemical properties of bitumens. The analyses are conducted within the LNTPB laboratory. The values represent the statistically significant average of the experiments. It also presents the outcomes of previous studies, facilitating a comparative analysis. The standards' requirements are also listed therein.

*Table 3: Marshall test results*

Test	Composition	Compression	Stability (Kg)	Creep (1/10mm)
1	7% HO	Cold	800	29.5
2	7% HO	Hot	500	25
3	5% HO	Cold	720	23
4	5% HO	Hot	600	55
5	9% HO	Cold	650	25.5
6	9% HO	Hot	380	45.5
7	7% HO 1,5 % cement 3% dolomie	Cold	875	46
8	7% HO 3% dolomie 1,5% cement	Cold (After 6 day)	960	68.5
9	7% HO 3% dolomie	Cold	820	40
10	7% HO 1,5% cement	Cold	775	45
11	7% HO <sub>treated</sub>	Cold	820	30
12	7% HO <sub>treated</sub>	Cold	800	38
13	<b>6% HO<sub>treated</sub></b>	<b>Cold</b>	<b>1,580</b>	<b>35</b>
14	9% HO <sub>treated</sub>	Cold	680	26
15	5,5% bitumen 35-50	Hot	510	56
16	<b>6% HO<sub>163</sub></b>	<b>Cold</b>	<b>1,660</b>	<b>28</b>
17	6% HO <sub>163</sub>	Hot	225	45
18	6% HO	Cold	1,140	36
19	6% HO 1,5% cement	Cold	2,220	31.5
20	6% HO 3% dolomie	Cold	1,240	29.5
21	6% HO 1,5% cement 3% dolomie	Cold	1,450	33
22	National route 2 sample (25/07/22)	Hot	700	34.5
23	<b>6% HO<sub>treated</sub></b>	<b>Cold</b>	<b>2,400</b>	<b>29.5</b>
24	6% HO <sub>treated</sub> 1,5% cement	Cold	1,300	35
25	6% HO <sub>treated</sub> 3% dolomie	Cold	1,380	29.5

26	6% HO 1,5% cement	Hot	700	30
27	6% HO <sub>treated</sub>	Hot	540	35.5

Table 3 compiles the various tests, thereby presenting the utilized formulas and providing the percentage of binder and additive. The mass in air and water of each specimen is listed therein. The compression type, whether cold or hot, is also noted in the table. The stability and creep of each specimen are documented within this table.

*Table 4: Comparison of Marshall cold mix results*

Designation	Current results	Specification	Previous results [3]
Binder percentage	6% HO <sub>treated</sub>	-	8,6% HO
<b>Stability (daN)</b>	<b>1,880</b>	<b>≥ 400</b>	<b>860</b>
Creep (1/10mm)	30.8	≤ 40	30.5

Table 4 presents the optimal formula from the Marshall test experiments. The average stability and flow values are mentioned. Additionally, a comparison can be made against the results of previous research as well as the required standards.

*Table 5: Duriez test results*

		Current result	Specification	Previous result [3]
Duriez test at 18°C	Stability after 7 days exposed to air	405 daN	≥ 250 daN	260daN
	Stability after 7 days in water	580 daN	-	190 daN
	Stability ratio	1.43	≥0.70	0.73
Duriez test at 0-5°C	Stability after 7 days exposed to air	1,590 daN	-	-
	Stability after 7 days in water	960 daN	-	-
	Stability ratio	0.60	-	-

Table 5 displays the results of the Duriez tests. The tests are conducted at temperatures of 18°C and 0-5°C. The average stability after exposure to air and after immersion in water is

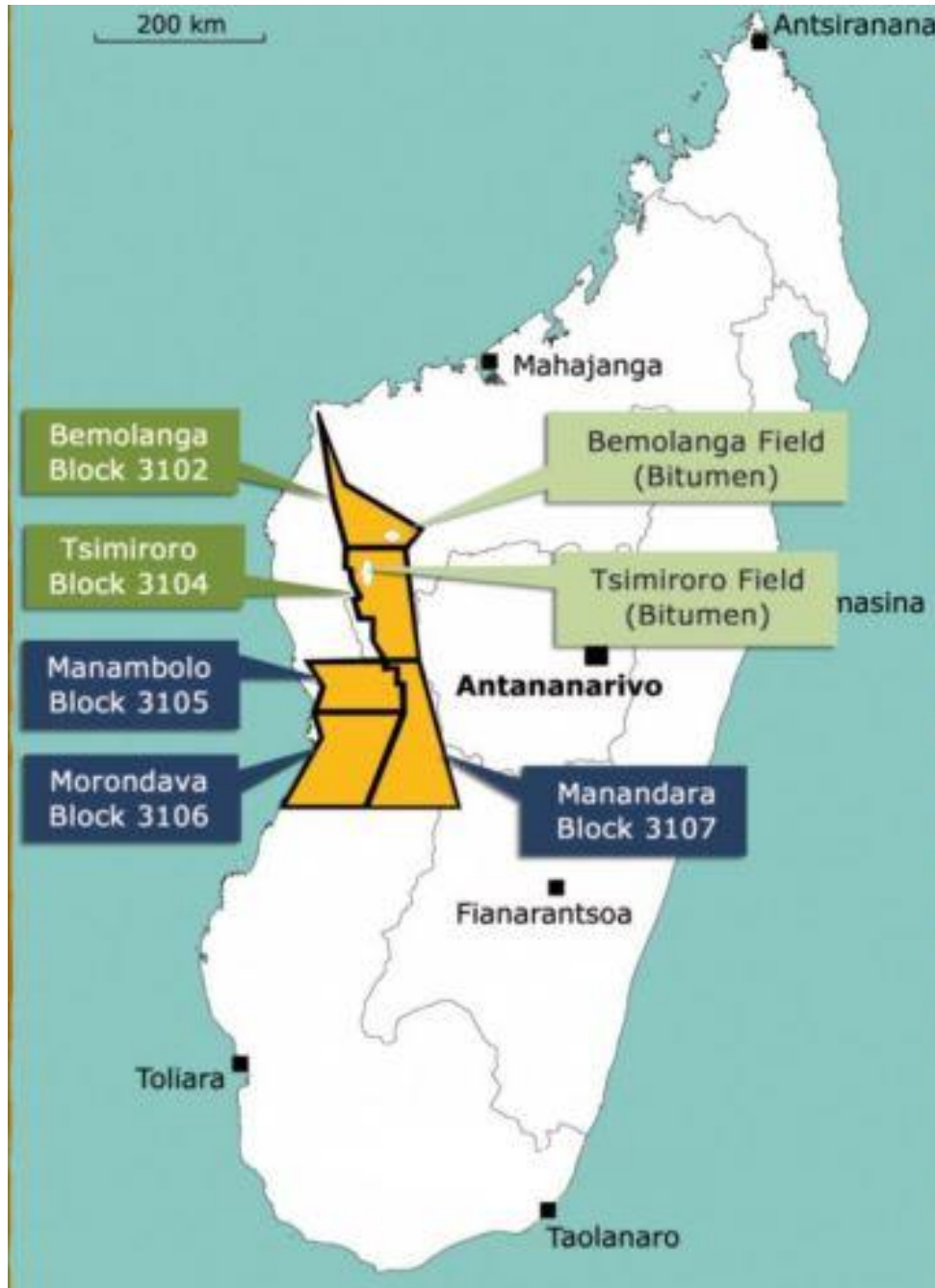
provided. The stability ratio is also listed in this table. Moreover, a comparison can be carried out against the results of previous research as well as the required standards.

*Table 6: Cost per kilometer based on binders*

	Heavy Oil	Bitumen (grade 60-80)
Aggregate volume	420 m <sup>3</sup>	420 m <sup>3</sup>
Binder percentage	6%	5%
Binder mass	66.77 tons	50.4 tons
Barrel mass	0.15 tons	0.18 tons
Number of useful barrels	430 barrels	300 barrels
Barrel Price (as of 08/01/2023)	\$100	\$266,66 (selling price in Madagascar)
Binder cost per 1 km	\$43,000	\$80,000

Table 6 presents the various calculated values for the cost of constructing one kilometer of road. The asphalt's dimensions are 1,000m in length and 7m in width. The asphalt's thickness is 0.06m. A comparison is made between the use of heavy oil and bitumen as binders.

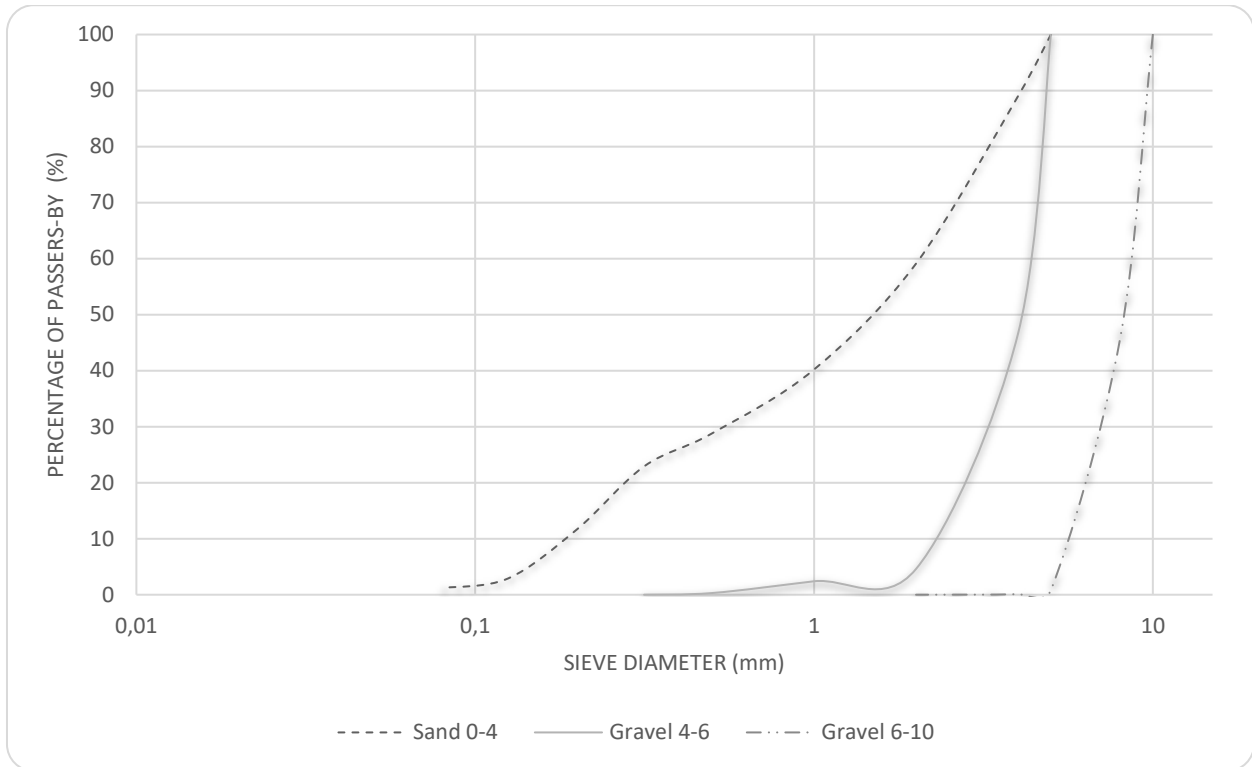
## 11 Figures



*Figure 1: Madagascar Oil's blocks in 2012*

*(Source: [11])*

Figure 1 depicts the geographical locations of the petroleum blocks explored by Madagascar Oil in the island nation in 2012. Of particular interest is Block 3104 of Tsimiroro, which serves as our primary focal point.



*Figure 2: Sieve size curves for limestone sample*

Figure 2 illustrates the particle size distribution curve of the limestone sample. The curve provides an analysis of the distribution of limestone based on its dimensions as it passes through various sieves.