Available online at www.ejournals.uofk.edu

UofKEJ Vol. 10 Issue 1 pp. 41- 48 (February 2020)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UofKEJ)

Investigating Pipe Culvert Failure in Baleela Oil Field in Sudan

Omer S. M. Hamza[1], Zain E. Eltybe[2], Omer M. Omer[3]

[1]Civil Engineering Department, Faculty of Engineering, [2]Road Construction Senior Engineer, Petro-Energy, [3]Road Construction Superintendent, Petro-Energy Co. Khartoum, Sudan,

(E-mail: omersiddigmustafa@gmail.com, zelabdeen@petroenergy-ep.com, omohyielden@petroenergy-ep.com)

Abstract: This paper thoroughly investigates failure cases of the constructed pipe culverts in Baleela oil field in west of Sudan. The paper provides technical recommendations and remedial measures. Common types of failures of pipe culverts and their appropriate measures were briefly discussed. The paper provides inspection based on extensive site survey and data record review to find out the main structural and hydrological causes of culverts failure. The site survey is conducted in the last two years while the data record review extended since 2011. The pipe culverts engaged in this study were 20 water streams each of them contain 3 to 8 pipe culverts. Failures of pipe culverts constructed in 9 locations during the last 9 years were evaluated in percentage. The investigation showed that various reasons caused failures of the studied culverts including volume of water flow, corrosion and scouring, floating trees and deformation in pipe culvert obtained from traffic load beside construction related reasons such as culverts assembly, poor construction, un-compacted backfilling and the backfilling soil type in addition to design related reasons such as improper design and pipe capacity. It could be concluded that the pipe culvert is the most economic water crossing structures for valleys of low water flow volume. Also pipe culverts are not suitable for wide shallow valleys.

Keywords: *Drainage, Culvert, Pipe, Stream.*

1. INTRODUCTION

Gravel roads in rural areas are necessary for transportation purposes. As these roads pass over lots of water streams in rural areas, crossing structures such as steel corrugated pipe culvert, concrete culvert and bridges are needed. The community's development depends on effective road networks and safe crossings. Because of their improper design and poor construction, many water stream structures likely sustain failures and damages from water runoff and large storms [1]. Failure on water crossing structures definitely results in road damages and almost closure. This failure has direct effect and economic burden to road users and isolates the surrounding communities.

Failures of roads in oil fields interrupt operations of oil industry companies and stop/delay the accessibility to their facilities such as drilling rigs, well sites, CPF, FPF and other facilities. In rural areas damages of roads isolate the inhabitants of the surrounding villages and influence emergency services from reaching people in need of help. Also it effects the local business income on roads route as a result of roads closure.

A culvert is a structure that allows water to flow under a road, railroad, trail, or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or other material. Culverts constructed in Baleela oil field are two types, corrugated steel pipes installed during the period from 2001 to 2019, and concrete box culverts constructed after 2014.

Culverts in general are used both as cross-drains to relieve drainage of ditches at the roadside and to pass water under a road at natural drainage and stream crossings. A culvert may be a bridge-like structure designed to allow vehicles or pedestrian traffic to cross over the waterway while allowing adequate passage for the water.

Common culverts come in many sizes and shapes including round, elliptical, flat-bottomed, open-bottomed, pear-shaped, and box-like constructions. The culvert type and shape selection is based on a number of factors including requirements for hydraulic performance, limitations on upstream water surface elevation, and roadway embankment height.[2]. The culverts engaged in this study are rounded corrugated steel pipes of different diameters, 0.6, 1.0, 1.6, 2.0 and 2.5 m.

2. LITERATURE SURVEY

In rural areas where the traffic volume is limited, gravel road could be suitable for transportation purposes. Many gravel roads were constructed in rural areas in Sudan and they served well for many years particularly those who had routine maintenance and upgrading. Gravel roads need upgrading at least every two years depending on traffic volume. Oil and gas operating companies in Sudan used gravel roads to facilitate their operations and they constructed gravel road nets in their fields in Heglig, Baleela, Palouge, etc. Meanwhile gravel roads cross wide rural areas which are surrounded by a lot of water streams and small rivers, they face serious challenges to establish safe cross-drains and bridges.

2.1 General

Culverts are widely used as cross-drains for ditch relief and to pass water under natural drainage and stream crossings. Culverts are made of concrete or metal (corrugated steel or aluminum), and plastic pipe is occasionally used, as well as wood and masonry. The type of materials used depends on cost and availability of these materials. Generally, concrete and metal pipes are more durable compared with plastic pipes. The culverts are commonly used in different shapes, namely round pipes, arch pipes, structural arch, and box depending on the site, the required span and the permissible height of backfill soil [3]. Culverts need to be properly sized and installed, and protected from erosion and scour. The key factors in culvert selection are that the culvert has adequate flow capacity, fits the site, and that the installation is cost- effective, [4].

2.2 Culvert Installation

Culvert installation for drainage crossings is quite important process for sustainability of the culvert, [3]. Important installation details include install culverts at natural stream grade, using quality, well compacted bedding and backfill material; and using inlet, outlet, and stream bank protection measures, [6]. Figure 1 shows pipe culvert installation at natural stream level. Bedding and backfill material for culverts is commonly specified as "select granular material". However, any soil of low moisture, mud, roots, expansive clay, and boulders can be used. Bedding material beneath the pipe should not have rocks larger than 3.8 cm [8]. Clay soil can be used if it is carefully compacted at a uniform near optimum moisture content [4].

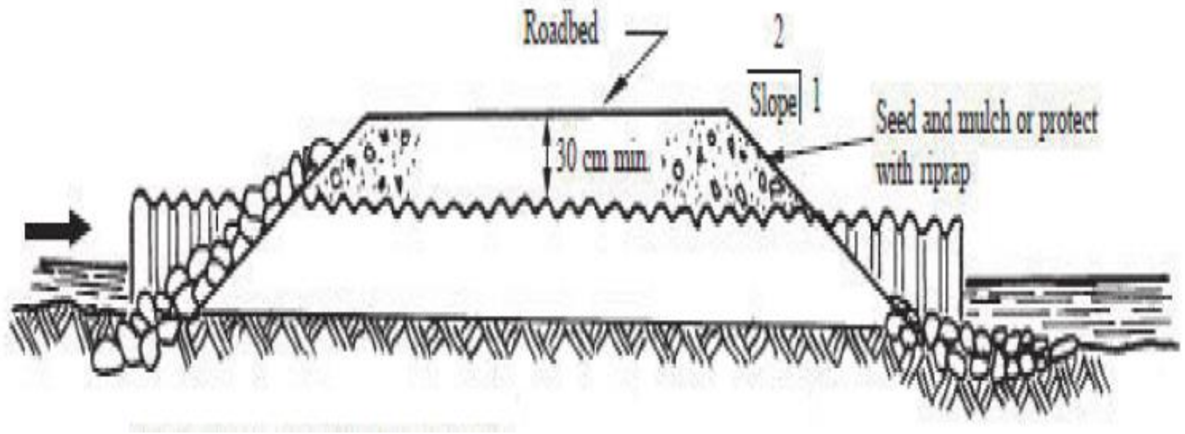

Fig. 1. Culvert at natural stream [3]

2.3 Failure on Culvert

Various reasons of failure on culvert including lack of maintenance, environmental, and installation-related failures, capacity related failures. Those failures causing erosion of the soil around and under the culvert, as depicted in Figure 9, and structural or material failures that cause culverts to fail due to collapse or corrosion of the materials from which they are made.[5]

Capacity related failures of culvert in some cases is accelerated by floating trees that blocks the inlet of culvert in some cases which cause high pressure. Figure 4 shows floating trees in culvert in Baleela.

Overflow water on the embankment and through the foundation of pipe culvert is the main contributor to the wear and damages of embankments [8].

Failures on culverts may occur suddenly. Sudden road collapses are often the result of poorly designed and engineered culvert crossing sites or unexpected changes in the surrounding environment cause design parameters to be exceeded. Water passing through undersized culverts will scour away the surrounding soil over time. This can cause a sudden failure during medium-sized rain events. Accidents from culvert failure can also occur if a culvert has not been adequately sized and a flood event overwhelms the culvert, or disrupts the road or railway above it.

Ongoing culvert function without failure depends on proper design and engineering considerations being given to load, hydraulic flow, surrounding soil analysis, backfill and bedding compaction, and erosion protection. Improperly designed backfill support around culverts can result in material collapse or failure from inadequate load support.[5]

For constructed culverts which have sustainable degradation or loss of structural integrity, rehabilitation using a reline pipe maybe preferred instead of replacement. Sizing of a reline culvert uses the same hydraulic flow design criteria as that of a new culvert, however as the reline culvert is meant to be inserted into an existing constructed culvert, reline installation requires the grouting of the annular space between the host pipe and the surface of reline pipe so as to prevent or reduce seepage and soil movement. Grouting also serves as a means in establishing a structural connection between the liner, host pipe and soil. Depending on the size and annular space to be filled as well as the pipe elevation between the inlet and outlet, grouting maybe required to be performed in multiple stages. As the diameter of the reline pipe will be smaller than the host pipe, the cross-sectional flow area will be smaller.

Failure of pipe culvert may occur due to deformation of pipes (Figure 2) which results from load of transportation. Such failure occur when the soils above pipe culvert are not capable to support transportation loads. Soils above pipe culvert should have suitable strength and compaction and should be of thickness not less than 30cm. thickness above pipe culvert depending on pipe diameter. Larger pipes require larger thickness.

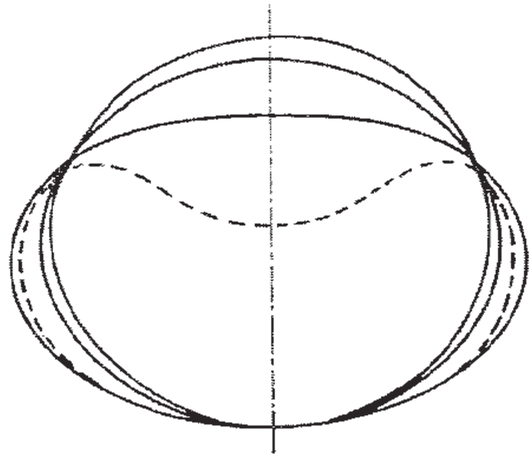

Fig .2. Stages during deformation of a flexible culvert [8]

Fig .3. Deformation in pipe culvert in Shag Yahia

Fig. 4. Floating tree in pipe culvert inlet in Sabreen

3. CASE OF STUDY

The aim of this study is to deliver extensive investigations to find out the structural and hydrological causes that lead to failures on pipe culverts. The study based on an extensive visual investigations of the constructed pipe culverts in Baleela oil field and the design and construction data. The investigations covered the embankment, inlets and outlets and foundations condition. It should be noticed that Petro-Energy had begun to install pipe culverts since 2001. Later after 2014 Petro-Energy replaced some pipe culverts by concrete box culverts in 13 different streams with different numbers of cells (2 to 7). Petro-Energy constructed concrete box culverts as a replacement of pipe culverts that subjected to high water flow volume to avoid numerous failures occuring on pipe culverts.

3.1 Project Description

Petro-Energy is an oil operating company that constructed a network of gravel roads cover its operations in block 6 in west Kordofan and the east part of west Darfur state. Those roads could be categorized into two types; main roads and access roads. The access roads connect well sites and minor facilities. While main roads connect large areas and major facilities such as oil fields, CPF, FPFs, camps, ets.

Large numbers of valleys and water streams of different sizes exist in Baleela oil field. The large amount of valleys resulted from rainfall discharge of the Nubian mountains towards the southern west direction. Roads are crossing many valleys of various sizes.

3.2 Investigation Approach

The investigation approach followed in this study based on data record review and site survey. The data record review started from 2011 while the site survey was extended for the last two years (2018 and 2019).

3.3 Field Survey

Observations and comments on the field investigation and data record review of pipe culverts are briefly discussed herein.

The field survey and data record review covered the constructed pipe culverts in the eastern area of block 6 which is known as Baleela oil field. The field survey covered the last 2 years while the data record review extended to 9 years.

Investigations in this study were conducted on 9 major water streams as seen in figure 5. The study conducted on Baleela new airport road (BNA), Sabreen road, Shag Yahia, Senitaya, ring road, BV#2 road kilo points 7 and 22, Hadida transit line road (HTL) and Jake road. Almost yearly failures on some pipe culverts were observed. Failures on pipe culvert of large diameters (1.2, 1.6 and 2m) are far most than that of small diameters (0.6 and 1m).

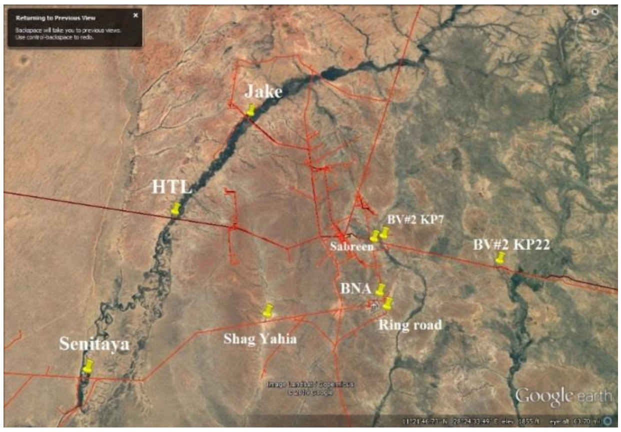

Fig.5. Google image of the studied pipe culvert area

The site survey showed that all pipe culverts failure and damages occur in the rainy season from May up to October. It is noticed that pipe culverts yearly suffer from serious damages in the first half of the rainy season. Beside the erosion and scouring, trees float at the beginning of rain seasons which lead to culvert closures or reduce culverts capacity. Reduction of culvert capacity to discharge water resulted in high water pressure causing pipe culvert failures in many cases.

Lately erosion protection made of stone pitching (Figures 4 and 10) were constructed in some pipe culvert locations to minimize erosion and to protect embankment. Stone pitching are used to construct walls, wing walls and aprons on both inlet and outlet. The stone pitching served well in the first 4-5 years. Beyond that they needed remedial maintenance due to high water pressure (Figure 10). It was noticed that walls of stone pitching were affected from the water flow on upper streams further than down streams. While aprons of stone pitching were affected further down streams due to hydraulic jump.

It is suspected that many failures in pipe culvert resulted from un-proper compaction of backfilling soils in common with type of backfilling soils. The geotechnical analysis of the soil gradation in this area showed that the main types of the original surface soils are almost silty sand, sandy gravel, and some of clay gravel. The soils also have very low plasticity which can be categorized as non-cohesive soils. Non-cohesive soils are not desired as backfilling materials.

About 15% of the constructed pipe culverts were not installed in the exact concerned water path. Pipe culverts which positioned incorrectly suffered many failures yearly due to scouring. Attempts to reposition pipe culverts were conducted after 2014. Reposition of pipe culverts reduced damages impact caused by water flow.

The field survey indicated that 7 locations of pipe culverts (2 in Jake, 2 in HTL, 2 in Sentaya and one in BV#2 KP7) have water flow further than the capacity of the pipe culverts. Those culverts were seriously damaged many times. After 2013 Petro-Energy decided to replace those pipe culverts by concrete box culvert with various number of cells according to water flow volume. Typical concrete box culvert is depicted in figure 22.

Water seepage through the connection between pipe culvert sheets were investigated. Water seepage also occurs due to losing some bolts and nuts of pipe culvert sheets. Water seepage affect pipe culvert performance over time and resulted in many partial and total failures. Water seepage between pipe culverts sheets were prevented by using plastic rubber sandwiched in between sheets as seen in figure 11. The rubber sheets were used in pipe culverts constructed after 2014. The site survey and data record showed that the use of this technique has significantly reduced failure of pipe culverts due to water seepage.

Fig .6. Pipe culvert assembly in Baleela warehouse

Fig .7. Pipe culvert installation in BNA road

4. RESULTS

4.1 Erosion

Analysis of data and site survey confirmed that mostly failures of pipe culvert resulted because of the high water flow volume. The high water flow volume caused corrosion and scouring on embankment. Almost 60% of pipe culverts failures caused by corrosion and scouring. It is remarked that scouring caused total damages in pipe culvert and resulted in road. Figure 8 shows partial damage in the downstream in Sabreen road. Figure 9 shows totally damaged pipe culvert in Baleela airport road in August 2019. The highest water flow volume in Baleela is between July and September every year but sometimes extended up to November.

It should be noted that stability of embankment depend on soil type and some other factors such as the compaction and side sloop. Cohesive soils likely sustain stability of pipe culverts when used as embankment and backfilling materials rather than the use of un-cohesive soils. Sharp sloped embankments are undesired when exist close to water streams. Certain slope of embankment is presented in figure 1. Embankment and backfilling soils in Baleela are almost made of non-cohesive soils. Almost 40% of embankment of roads near water streams in Baleela constructed with sharp slope.

Fig .8. Erosion in the outlet in Sabreen

Fig .9. Erosion of soil due to pipe culvert failure in BNA road

Fig 10: Erosion in protected pipe culvert in HTL road

4.2 Improper Installation

Improper installations of several pipe culverts were detected during the site investigations. Commonly installation of pipe culverts in Baleela oil field can be divided into two stages. The first stage is culvert assembly held in warehouse as seen in figure 6 then the assembled pipes transported to site where to be installed as seen in figure 7. Assembly of pipe culvert is gathering the individual sheets together by bolts, nuts and washers.

The site investigations detected that some bolts were missed and some nuts were fastened insufficiently. Insufficient fastening of nuts and missing bolts likely generate water seepage through the bolts holes. On the other hand some of pipe culverts were found wrongly fabricated. Sheets have been fabricated incapable with the water direction. It is important to consider the water direction when installing pipe culverts.

4.3 Improper Design

According to data record review there are several design related faults found in many pipe culverts. Pipe culvert contents (sheets, bolts, nuts and washer) are imported to Baleela oil field through venders yearly. It should be noticed that Petro-Energy enquires venders to enhance design of pipe culvert materials yearly.

Before 2014, road construction supervisors detected some failures on pipe culverts were caused by water seepage through the connection of pipe culvert's sheets. The sheets made of metals are only connected together by 4 to 5 bolts. Rubbers sandwich were suggested to ensure proper connections of sheets and to prevent water seepage. The rubbers which depicted in figure 11 were made of plastic sheets of 10cm width and length as pipe culvert sheets. The rubbers which have adhesive on both sides sandwiched between individual sheets. It was reported that the new techniques remarkably reduced failure on pipe culvert caused by water seepage.

Fig. 11. Rubber sheets sandwiched in pipe culvert in BV#2 KP7.

5. DISCUSSION

Failure of pipe culverts in Baleela oil field during the last 9 years is presented in table 1. The data was collected for the main water valleys in Baleela. The data presented in table 1 is analysed and plotted as depicted in figures 12 to 21. The data collected in the study to evaluate failure on pipe culverts are analysed as percentage wise. It was observed that 4 locations of pipe culverts were not subjected to any damages due to replacing the pipe culverts by other masonry structures such as concrete box culvert constructed in Senitaya, HTL and Jake and Irish crossing constructed in BV#2, Kilo point 7. The concrete box culverts as seen in figure 22 were constructed after 2013 rain season while the Irish crossing was constructed after 2016 rain season. Those masonry structures were constructed after many serious failures in the specific pipe culverts.

It was noticed that most failures in pipe culverts occurred in 2013 as shown in figures 14 and 21. According to Sudan Meteorological Authority data 2013 recorded the most rain fall in Sudan compared with the latest years up to 2008. Additionally some practical techniques including rubber sheets were not used yet. Many roads and highways around Sudan were damaged and closed at least for a while in 2013. In Baleela in 2013, two main roads (Jake and HTL roads) were totally closed for more than a month due to serious failure in pipe culverts (100% failure) beside three other main roads were closed due to serious damages in pipe culvert (90% failure).

It was observed that remarkable improvement in pipe culverts performance during 2014 subsequently gradient deterioration in performance was noticed after 2014. Construction of concrete box culvert in earlier 2014 in some locations replacing the pipe culvert showed evident improvement.

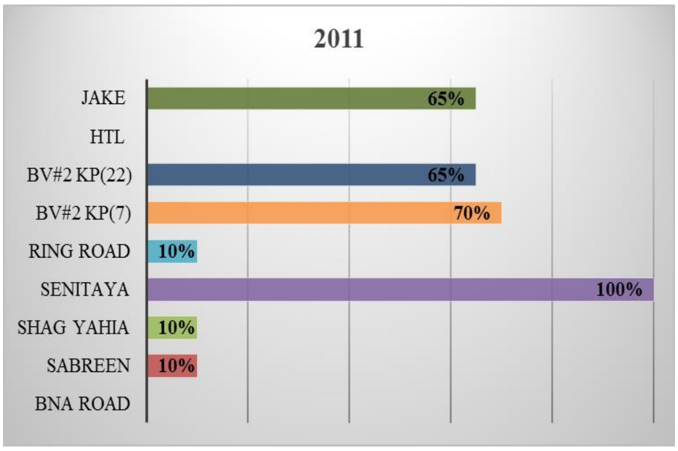

Fig .12. Failures in some pipe culverts in 2011.

Table 1. Yearly percentage damages on some pipe culverts in Baleela.

Location of Pipe culvert	2019	2018	2017	2016	2015	2014	2013	2012	2011
BNA road	100%	20%	5%	2%	2%	3%	18%	0%	*
Sabreen	10%	100%	15%	8%	10%	7%	75%	50%	10%
Shag Yahia	10%	100%	40%	45%	25%	40%	65%	30%	10%
Senitaya	0%	0%	0%	0%	0%	0%	40%	100%	100%
Ring road	60%	65%	65%	55%	40%	10%	90%	10%	10%
BV#2 Kilo Point 7	0%	0%	0%	55%	8%	8%	95%	90%	70%
BV#2 Kilo Point 22	30%	100%	30%	35%	10%	10%	90%	75%	65%
HTL	0%	0%	0%	0%	0%	0%	100%	*	*
Jake	0%	0%	0%	0%	0%	0%	100%	75%	65%

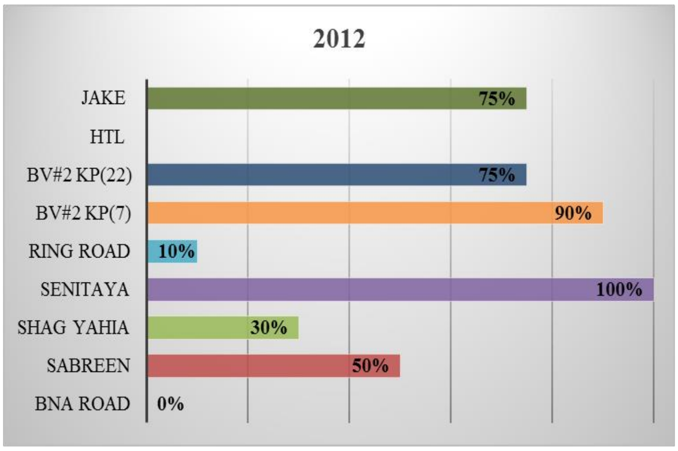

Fig .13. Failures in some pipe culverts in 2012

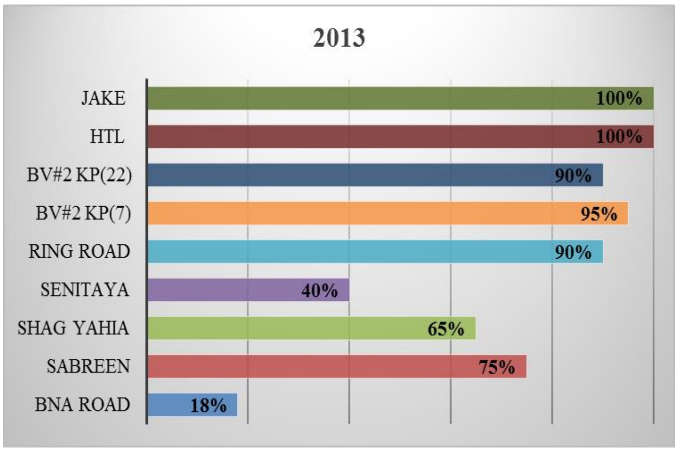

Fig .14. Failures in some pipe culverts in 2013

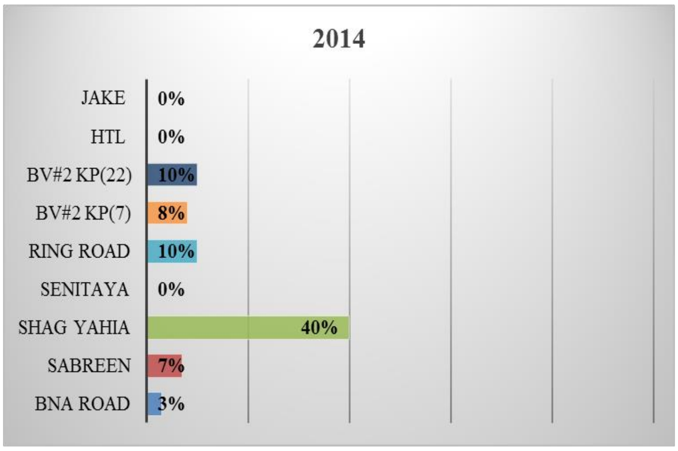

Fig .15. Failures in some pipe culverts in 2014

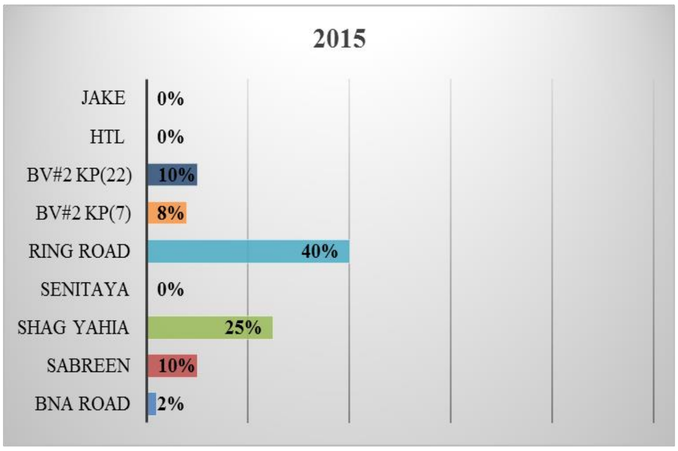

Fig 16. Failures in some pipe culverts in 2015

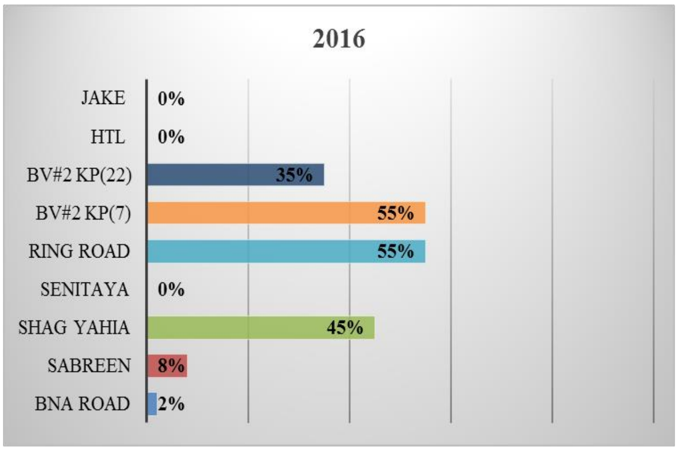

Fig .17. Failures in some pipe culverts in 2016

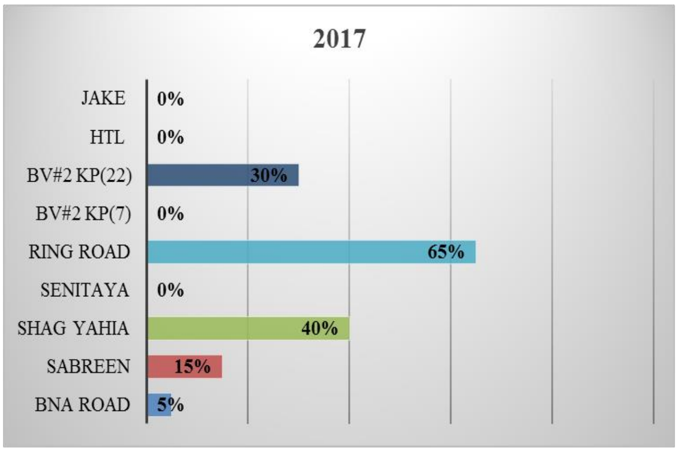

Fig .18. Failures in some pipe culverts in 2017

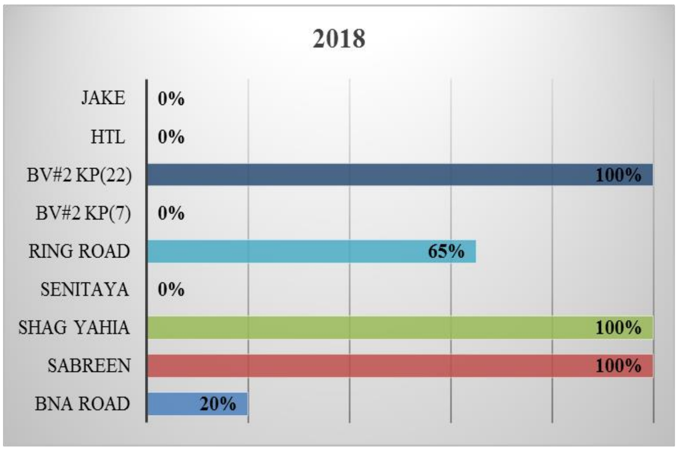

Fig .19. Failures in some pipe culverts in 2018

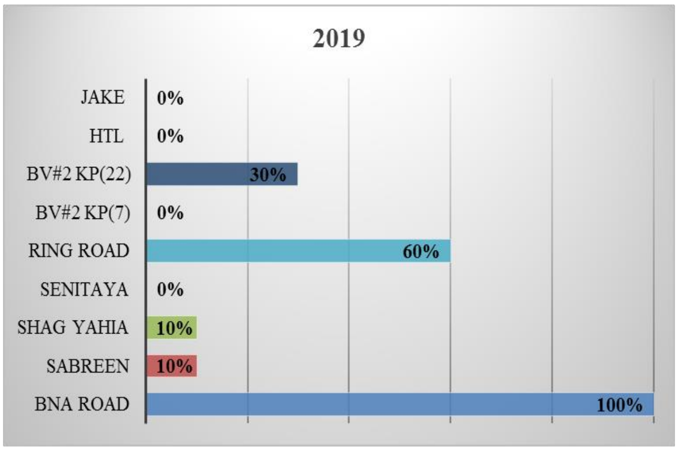

Fig .20. Failures in some pipe culverts in 2019

Figure 21 shows annual failure of pipe culvert in the main 9 valleys in percentage. The figure was plotted using the average failures in all valleys each year in percentage. From the figure it can be noted that 2011, 2012 and 2013 were recorded the most horrible failures of pipe culvert compared with other concerned years. Remarkable improvement can be observed in 2014 then gentle decrease in performance appeared. In recent 6 years 2018 showed many failures on pipe culverts. 3 main roads were totally damaged and closed (BV#2 Kilo Point 22, Shag Yahia and Sabreen). Failures occurred in those pipe culverts due to high water volume, floating trees and lack of backfilling soils to support pipe culvers. Later in 2019 those pipe culverts were protected using stone pitching.

In 2019 an improvement in pipe culverts performance was detected particularly after construction of many stone pitching (erosion protection). Only BNA road was subjected to total damage and the road was closed for a while. After deep investigations, unexpected changes in the surrounding environment were discovered. The changes were made by digging trench on the upstream of BNA pipe culvert for security reasons. The trench was completed near the end of 2018 and it affected the road in autumn in 2019. The road was repaired and stone pitching was constructed in early 2020.

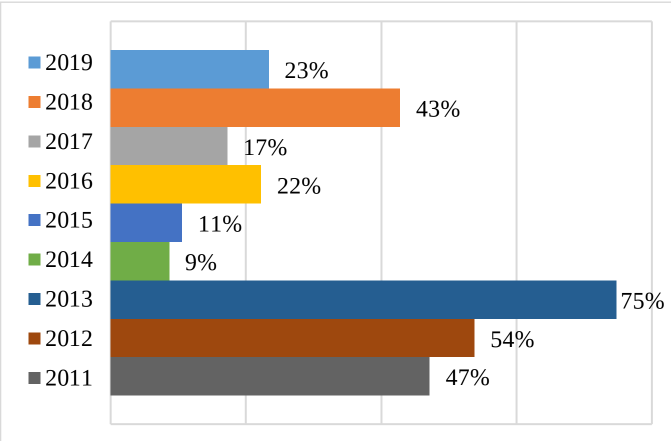

Fig .21. Annual failures of pipe culverts in Baleela in percentage

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study investigates failure on pipe culvert in Baleela oil field. The concerned pipe culverts are made of corrugated steel pipes. The study based on extensive site survey and comprehensive data record review to determine the main structural and hydrological causes of pipe culvert failure. The site survey was conducted on main nine locations of pipe culverts in Baleela for two years. The data record review involves the last nine years. The site survey focused on BNA road, Sabreen road, Shag Yahia, Senitaya, ring road, BV#2 road KP7, BV#2 KP22, HTL road and Jake road. Pipe culverts constructed on these valleys contain clusters of different diameter pipes from 0.6 m to 2.0 m. Each cluster consists of 3 to 8 pipes. The methodology followed in the study to evaluate failure on pipe culverts is based on the degree of failure in the concerned road as a percentage.

The site survey and data record review showed that pipe culverts constructed in Baleela served well despite of numerous failures that occurred on many pipe culverts. Some of pipe culverts totally failed and damaged. It is recorded that some pipe culvert failed and reconstructed many times.

The site survey and data record review indicated that significant improvement in pipe culvert performance was observed recently (after 2013 as seen in figure 21) due to improvement of design, fabrication and installation of pipe culverts.

High volume of water flow during the rain season is the main cause of failures of pipe culvert in Baleela oil field. High volume of water flow resulted in erosion and scoring of embankment next to pipe culvert. Other cause of failure of pipe culvert recorded is the floating trees. Floating trees reduces the efficiency of pipe culverts to discharge water and in some cases (small pipe diameter) completely blocked the pipe culvert. Further causes of failure in pipe culvert observed include improper construction and design.

6.2 Recommendations

Further hydrological studies to determine water flow volume on valleys help to select certain crossing structures along with selecting adequate size of pipe culvert. Pipe culverts are not suitable for very high water flow volume. For such purpose concrete box culvert as that depicted in figure 22 would be the recommended choice.

Proper installation of pipe culvert reduces failure and damages. Proper installation of pipe culvert depends on type of the backfilling soils and compaction as well. Cohesive soils are recommended to be used as backfilling soils if compacted at moisture content near the optimum. Cohesive soils are recommended for their desired properties such as low permeability, solidarity, decent consistency and strength.

Annual remedial maintenance of pipe culvert is recommended. Annual maintenance is recommended particularly before rainy season starts. Lack of maintenance likely increases the failure possibility of pipe culverts. Floating trees which stuck in the inlet of pipe culvert should be removed promptly.

To avoid deformation of pipe culvert such as that shown in figures 2 and 3 backfilling soils above the pipe culvert should be of thickness of at least 300 mm. Thickness of soil above the pipe culvert depends upon the pipe diameter. The larger diameter pipes requires larger thickness of soil above. Erosion protection (stone pitching) is recommended to avoid scouring. Construction of stone pitching protect the embankment on both inlet and outlet. However, long-lasting stability of pipe culverts can be assured.

Further improvement in pipe culvert quality. Good quality of metal that makes pipe culvert contents (sheets, bolts, nuts and washers) help to reduce deformation and water seepage. The recommended pipe quality are to be of thickness not less than 3 mm, bolt holes not near the edge and waves of length not more than 60 mm with height not more than 30 mm. Pipe culverts of larger waves have less strength than pipes which have smaller waves.

Fig .22. 6 cells concrete box culvert in HC pipeline road

REFERENCES

[1] J. Levine. An economic Analysis of Improved Road-Stream Crossings. The Natural Conservancy, Adirondack Chapter, Keene Valley, NY, Aug. 2013

[2] Taylor, Karl (2010). "Thacka Beck Flood Alleviation Scheme, Penrith, Cumbria- Measured Building Survey of Culverts". Oxford Archaeology North.

[3] G. Keller and J. Sherar. Low-Volume Roads Engineering, Best Management Practices Field Guide. Produced for US Agency for International Development (USAID) In Cooperation with USDA, Forest Service, International Programs & Conservation Management Institute, Virginia Polytechnic Institute and State University, July 2003.

[4] Montana State University. Montana Forestry Best Management Practices. Montana State University Extension Service. July BMPs also produced by Montana Department of State Lands in 1992.

[5] Architectural Record CEU ENR (2013). "Stormwater Management Options and How They Can Fail" (Online Education Course), McGraw Hill Construction Architectural Record-engineering News Record.

[6] J. M. Normann; R. J. Houghtalen, W.J.; Johnston. Hydraulic design of highway culverts. Hydraulic Design Series No.5. Tech. Rep. No. FHWA-IP-86-15 HDS 5. September. McLean, VA: Department of Transportation, Federal Highway Administration, Office of Implementation, 1998, 265pp. (Online) http://www.fhwa.dot.govibridgeihydpub.htrn.

[7] M. G. Spangler, and R. L. Handy, Soil Engineering. 3rd edition. Harper and Raw.

[8] Magdi M. E. Zumrawi, Investigation of failures in Wadi-Crossing pipe culverts, Sennar State, Sudan. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering. Vol 10, No; 8, 2016.