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The Use of New Condition Assessment Technologies for Selecting Trenchless Rehabilitation of Wastewater Networks in Ras Al Khaimah, UAE

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ABSTRACT
The Ras Al Khaimah Wastewater Authority (RAKWA) manages wastewater collection and treatment of sewerage in the emirate of Ras Al Khaimah (RAK) – the fourth largest of seven emirates of the United Arab Emirates (UAE). Having the most fertile soil in the country, due to a larger share of rainfall and underground water streams from the Hajar mountains, combined with a growing number of resorts taking advantage of Gulf beaches, RAKWA is undertaking a series of major wastewater rehabilitation and expansion projects supporting a population of nearly 420,000 people.

Representing over 14.5km of recently installed plastic and fiberglass reinforced pipe, RAKWA targeted its City West Trunk Main, Mairid Network and Force Main Network – Area 1 Project, a currently 'inactive' network, for addition to the city's growing underground wastewater network, requiring innovative condition assessment, prior to its addition to the collection system.

RAKWA engineers had noticed numerous sections of the 'new' network were experiencing high levels of infiltration, initially approved by high resolution CCTV cameras. Located on the Arabian Sea, tidal infiltration is a constant threat resulting in infiltration and exfiltration. As a result, prior to connecting lateral services to the network, RAKWA decided to incorporate Focused Electrode Leak Location (FELL) to identify and quantify specific leak locations for Fiberglass UV-Cured Trenchless Rehabilitation.

FELL had been recommended in a recent Masterclass by UK-based WRc and is supported by ASTM F2550, leading to RAKWA's decision to use both IBAK Panorama CCTV and FELL technologies. While Gulf authorities have commonly relied on CCTV of their pipes, defects at joints and manhole connections many times have gone unnoticed, adversely affecting network performance.

This paper shares results from the first major benchmark of CCTV & FELL technologies in the Gulf and discuss selection parameters to conduct 3.5km of UV-cured CIPP and 310 patches or sectional liners.

INTRODUCTION
The Ras Al Khaimah Wastewater Authority (RAKWA) faced a challenge: when and how to connect residential and commercial businesses in the Al Mairid area to the sewerage network covering over 550 plots. Customers looked forward to eliminating septic tanks that frequently resulted in foul odours from regular tank emptying and cleaning, and occasional overflow during heavy rains.

Yet, despite the installation of new plastic and fiberglass reinforced sewer pipes, significant levels of tidal infiltration were occurring – without a single home or business connected to the system.

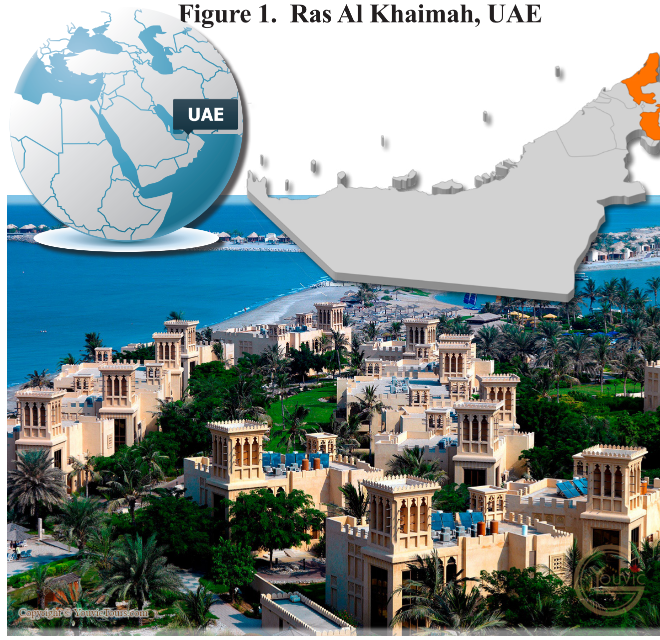
With 'new' sewers already fully infiltrated, without a single customer connection, and the need to prioritise repairs and rehabilitation without risking repeating past errors, RAKWA leadership needed to either utilise legacy camera-based visual optics or use untested high technology-based low voltage conductivity to find leaks. So, RAKWA decided to do both.

ABOUT RAS AL KHAIMAH, UAE

Representing the fourth largest Emirate covering an area of 2,486 square km (960 sq mi), or nearly 3 percent of the total UAE land area, Ras Al Khaimah, which means 'Top of the Tent' in Arabic, is located near the northernmost point of the United Arab Emirates, and shares a mountainous border with the Sultanate of Oman and three other Emirates which are Fujairah, Sharjah, and Umm Al Quwain, as shown in Figure 1.

Located on the waters of the Arabian Gulf with 64 km (40 mi) of sandy coastline, supporting a population of 420,000, average temperatures range from 12 to 25 °C (54 to 77 °F) in January and 29 to 43 °C (84 to 109 °F) in July. However, temperatures often reach 45 °C during summer months, reaching its highest recorded temperature of 48.8 °C (119.8 °F). Rains occur rarely, and only in winter, with snow reported in December 2004, January 2009 and February 2017 at the peak of Jebel Jais, the highest mountain in the UAE.

Figure 1. Ras Al Khaimah, UAE



CITY WEST TRUNK MAIN, MAIRID NETWORK AND FORCE MAIN NETWORK PROJECT

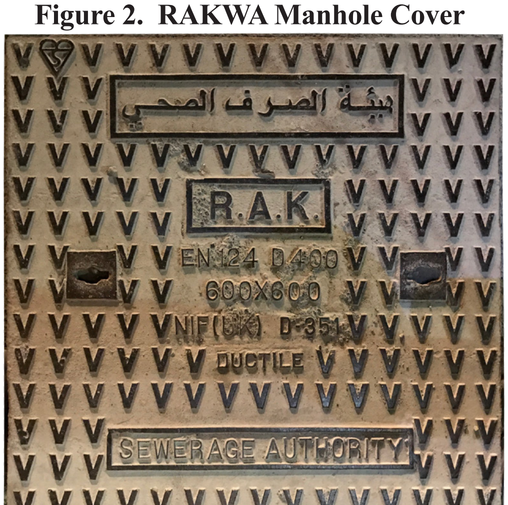
Representing over 14.5km of recently installed plastic and fiberglass reinforced pipe, RAKWA targeted its City West Trunk Main, Mairid Network and Force Main Network – Area 1 Project, a currently 'inactive' network, for addition to the city's growing underground wastewater network, requiring innovative condition assessment, prior to its addition to the collection system.

RAKWA engineers had noticed numerous sections of the 'new' network were experiencing high levels of infiltration, illustrated in Figures 2 & 3, initially approved by high resolution CCTV cameras. Located in close proximity to the Arabian Sea, tidal infiltration is a constant threat for infiltration and exfiltration.

As a result, prior to connecting lateral services to the network, RAKWA decided to incorporate Focused Electrode Leak Location (FELL) to identify and quantify specific leak locations for Fiberglass UV-Cured Trenchless Rehabilitation.

A new technology that had never been used in the Gulf, referred to as Focused Electrode Leak Location (FELL) or Low Voltage Conductivity, had been recommended in a recent Masterclass presented by UK-based Water Research Centre (WRc) plc. Supported by the American Society of Testing and Materials (ASTM) F2550, RAKWA leadership decided to use both FELL technology and traditional camera-based visual optics, utilising iBAK's Panorama camera for the project. Representing the largest CCTV | FELL benchmark test of its kind in the world, RAKWA looked forward to automatically comparing pre- and post-rehabilitation effectiveness, not available by using CCTV cameras.

Figure 2. RAKWA Manhole Cover



مؤسسة الصرف الصحى
Wastewater Agency

Figure 3. Surcharged 'Inactive' Sewer Main

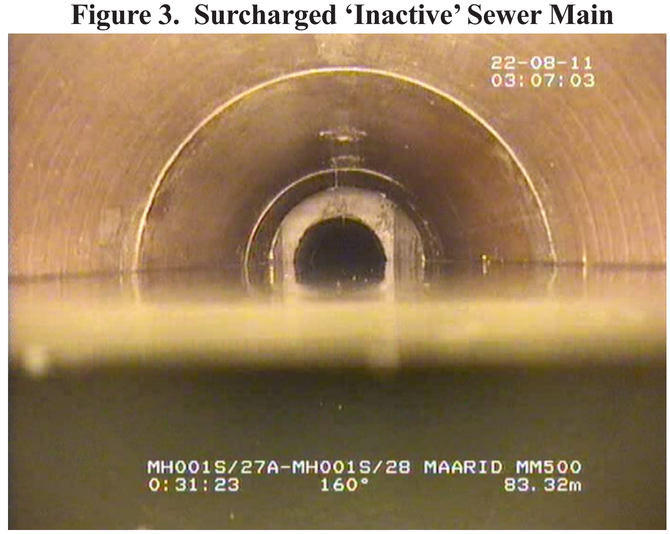


Figure 4. 15km (9.3mi) City West Trunk Main and Force Main Network – Area 1 Project

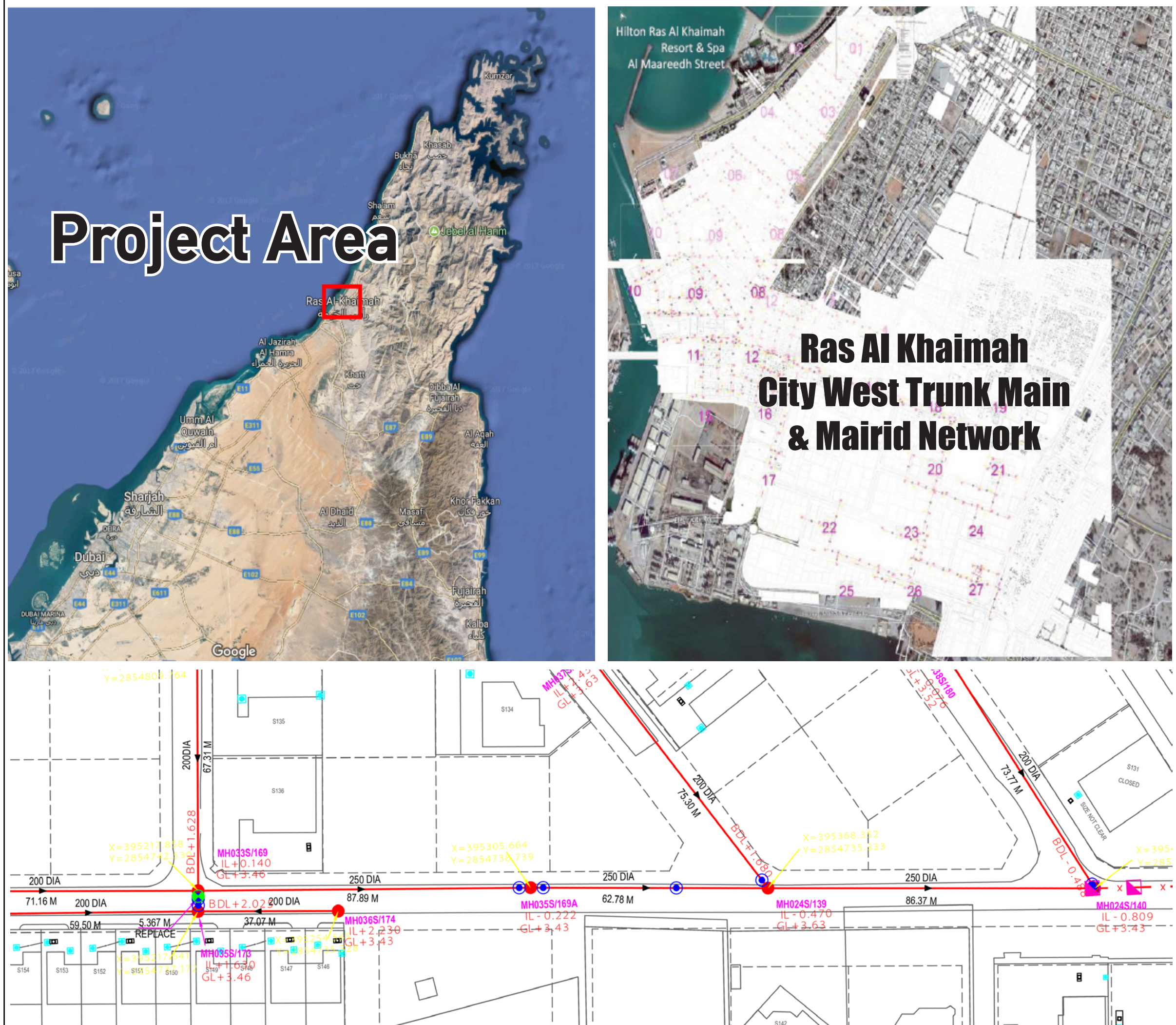


Figure 5. FELL Technology in Ras Al Khaimah

PROJECT SCOPE

As illustrated in Figure 4, RAKWA wished to identify specific locations of the 'inactive' network to undertake targeted trenchless rehabilitation and patch repairs, based on relevant condition assessment data from legacy CCTV inspection and next generation FELL machine-intelligent tethered instrumentation.

Issuing a formal tender for a selected contractor to undertake a 15km (9.3mi) investigation and complete repairs and rehabilitation in consultation with RAKWA's consulting engineer, Riyadh-based International Aramoon Co., Ltd. (IAC) was selected to complete visual inspection using German-manufacturer iBAK Panorama 360-degree camera technology and FELL machine-based instrumentation using American-manufacturer Electro Scan Inc.

Due to the requirement for CCTV and FELL inspection to utilize a common measurement system for positioning defects, FELL technology was retrofit into a Rausch manufactured CCTV van as show in Figure 5.

CCTV | FELL BENCHMARK RESULTS

Visual inspection has been a mainstay in RAKWA's condition assessment strategy, to assess the condition of its sewer mains. In the past, infiltration sources were difficult to identify because CCTV inspections needed to be completed with low or no flow conditions.

Given high groundwater areas and the invasive dynamics of tidal infiltration that can often impact sewer mains up to 2km away from ocean or waterways, it was often necessary to bypass flows of sewers to create lower flow conditions to identify defects. Video inspections can also fail to recognize defects in the sewer that contribute infiltration unless the CCTV occurs when infiltration is active.

In contrast to manual-based CCTV inspection, FELL inspection incorporates a machine-intelligent capability to automatically identify and quantify defects without third-party data interpretation or reliance on expert technicians to identify, classify, or code defects.

A detail review was made for each sewer main and summarized in Tables 1, 2 and 3. CCTV and FELL readings were compared for each sewer main, including side-by-side analysis showing locations of each defect. The uniformity of defects shown by FELL testing indicated a 100% correlation to pipe joints, with only minor discrepancies in comparing CCTV defects not found by FELL which occurred when insufficient water levels were not achieved in the field attributed to high rates of pipe exfiltration.

Table 1. Comparison of CCTV and FELL Results

SUMMARY	CCTV	FELL
Number of Sewer Mains Surveyed	211	211
Number of Meters Tested[1]	14,836	14,586
Abandoned Surveys	31	0
Zero Defect Observations	27	0
Single Defect Observations	40	0
Total Defects	673	2,101
Liters Per Second Defect Flow	NO	YES

[1] Discrepancy in distance due to CCTV survey abandonments and requirement to televise from opposite manhole.

Table 2. Summary of FELL Defects

Total Number of Defects				Defect Flow (Liters Per Second)			
Small	Medium	Large	Total Defects	Minor	Moderate	Severe	Total
1,067	494	540	2,101	26	80	64	170

Basic components of Plastic Pipe and common pipe defects are shown in Figures 6, 7, & 8, with examples CCTV and FELL results for the same sewer main provided in Figures 9 & 10.

Table 3. Summary of CCTV Defects, By Major Category

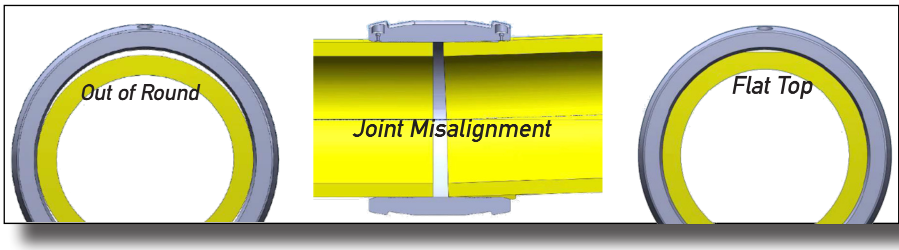
Broken Pipe, Break or Collapse										Infitration					Abandoned Inspections									
Broken Pipe, Break or Collapse, Length - 0mm	Broken Pipe, Break or Collapse, Length - 2mm	Broken Pipe, Break or Collapse, Length - 3mm	Broken Pipe, Break or Collapse, Length - 4mm	Broken Pipe, Break or Collapse, Length - 5mm	Broken Pipe, Break or Collapse, Length - 15mm	Broken Pipe, Break or Collapse, Length - 25mm	Broken Pipe, Break or Collapse, Length - 26mm	Broken Pipe, Break or Collapse, Length - 87mm	TOTAL BROKEN OR COLLAPSED PIPES	Infiltration - Gushing	Infiltration - Flowing	Infiltration - Sweating	Ingress of Soil	TOTAL INFILTRATION OBSERVATIONS	Abandoned Survey - Poor Visibility - HIGH WATER LEVEL	Abandoned Survey - Obstructed Rubber Seal / JT Displace	Abandoned Survey - Camera Obstructed pr Backdrop	Abandoned Survey - Opposite End Reached	Abandoned Survey - Camera Flipped or Stuck	TOTAL ABANDANDED INSPECTIONS	Total Fissures, Cracks	Total Deformations	Total Displaced Joints	TOTAL STRUCTURAL DEFECTS
10	6	6	1	1	1	2	1	1	29	16	13	16	1	46	5	9	13	0	4	31	27	5	535	673

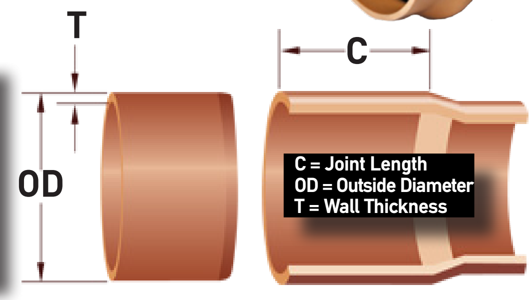
Source: Aramoon International Co., Ltd., CCTV Inspection using IBAK Panorama camera.

CCTV | FELL DEFECT IDENTIFICATION IN PLASTIC PIPES

The Gulf states utilise an abundance of plastic pipe for sanitary sewer and water installations, including High Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC). While the utmost in care is used in the manufacturing process, transportation, installation, and prolonged heat, prior to pipe laying, can play havoc with newly installed pipes, as shown below. Poor installation is the Number 1 cause for most pipe defects, especially in the case of poorly placed gaskets and improperly sealed joints.

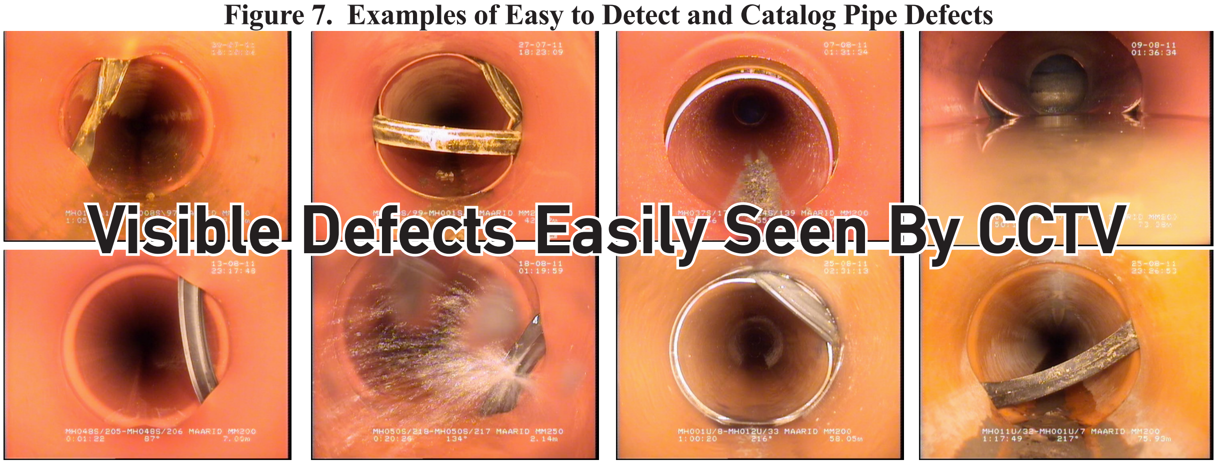
Figure 6. The Basics of Plastic Pipes





Easy to Detect 'Visual' Problems. A detailed review of Post-Installation / Pre-Commission of PVC sewer pipes can show obvious problems that should not be identified months or years after installation. Improperly sealed joints, poorly placed gaskets, and collapsed pipes should never be accepted if properly evaluated prior to acceptance, as shown in Figure 7 (*Below*).

Figure 7. Examples of Easy to Detect and Catalog Pipe Defects



'Invisible Sources' of Pipe Leakage Missed By Closed-Circuit Television (CCTV) Inspection. A key finding of the RAKWA condition assessment project was the confirmation of 'invisible' defects, i.e. defects at joints not readily observed by CCTV operators, QA/QC personnel or consulting engineers, as shown in Figure 8 (*Below*).

Figure 8. Examples of Difficult to Detect and Catalog Pipe Defects

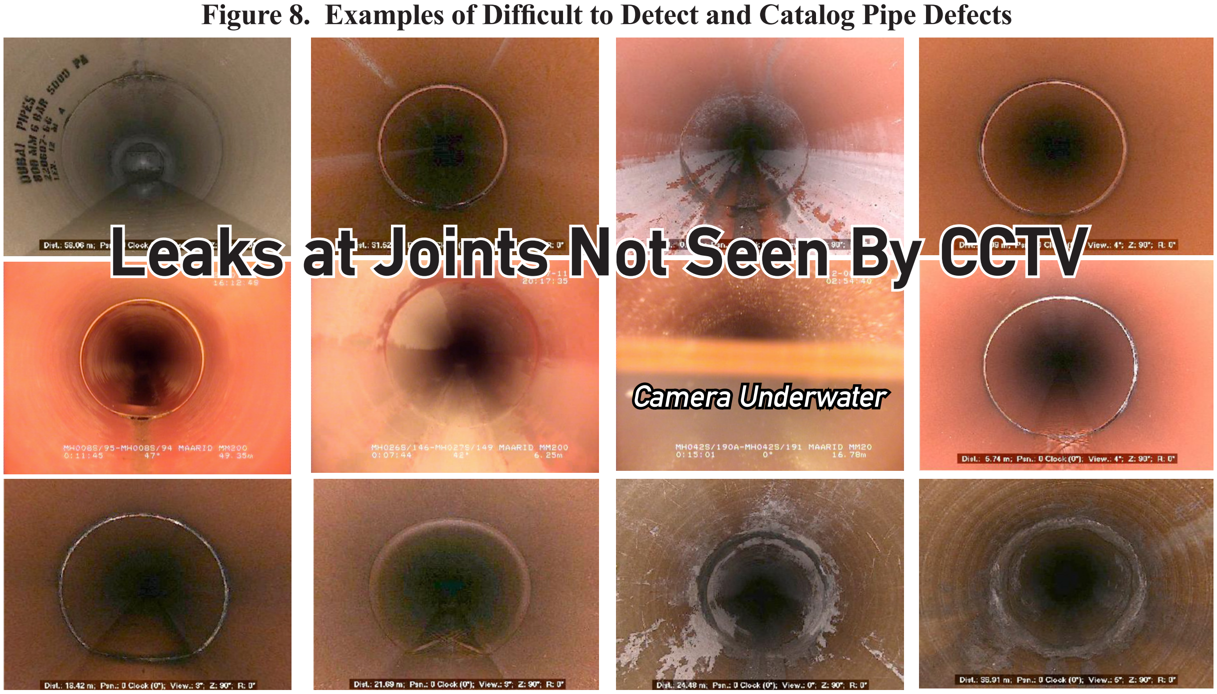


Figure 9. Example CCTV Inspection Results Using iBAK Panorama Camera

AREA 1, INACTIVE WASTE WATER NETWORK REHABILITATION

RAS AL KHAIMAH

RAKWA
RAK Wastewater Authority

MWH. BUILDING A BETTER WORLD

Hills & Fort Construction L.L.C

IAC EMIRATES

Section report

Section		**Top manhole**	MH011Z 54	**Insp. no.**	147
MH011Z 54 - MH024Z 100		**Bottom manhole**	MH024Z 100	**Insp. date**	06/09/2017
		Insp. direction	Down direction of flow		

Videotape	RAK A-202-44		
Videostart	00:00:00	**Place**	RAK -A1-SW-01
Videoend	00:04:30	**District**	RAK
Insp. reason	For sewer system records	**Street**	RAK
Way of insp.	Panoramo	**Owner**	RAKWA
Sewer no.		**Operator**	ERWIN M.
Year of const.		**Attendants**	RAKWA (HILLS AND FORT)
Profile	Circular cross-section	**Type of terrain**	Street, road
Height	250 mm	**Sewer system**	Wastewater
Width	250 mm	**Material**	Polyvinyl chloride
Pipe length		**Inter. protec.**	
Section length	112.35 m	**Description**	
Insp. length	113.60 m		
Up invert elevation	-0,23 m	**Category**	Service
Down invert elevation	-,68 m		

Photo	Video	Dist./m	G	Condition	C	Description
669	00:00:00	0.00		BCD A		Start node type, manhole
	00:00:10	0.20		BDD A		Water level, clear effluent, Height = 5%
670	00:00:20	0.90		BAJ B		Pos: 12- 6; Displaced joint, radial, Distance = 24mm
671	00:00:30	13.80		BDA		Pos: 12; General photograph
672	00:00:40	19.70		BDA		Pos: 12; General photograph
673	00:00:50	21.50		BAF A A		Pos: 3; Surface damage, increased roughness, mechanical damage
674	00:01:00	23.80		BBB B		Beginning > Pos: 7- 5; Attached deposits, grease, reduction of cross-section = 2%
675	00:01:10	25.20		BBC A		Beginning > Pos: 6; Settled deposits, fine, Height = 2%
676	00:01:20	27.30		BBC A		End > Pos: 5; Settled deposits, fine, Height = 2%
677	00:01:30	27.50		BAF A A		Pos: 8; Surface damage, increased roughness, mechanical damage
678	00:01:40	33.60		BBB B		End > - 5; Attached deposits, grease, reduction of cross-section = 2%
679	00:01:50	34.00		BAF A A		Pos: 3; Surface damage, increased roughness, mechanical damage
680	00:02:00	45.20		BBB B		Beginning > Pos: 7- 5; Attached deposits, grease, reduction of cross-section = 2%
681	00:02:10	51.20		BBB B		End > Pos: 12- 5; Attached deposits, grease, reduction of cross-section = 2%
682	00:02:20	55.70		BBC A		Beginning > Pos: 6; Settled deposits, fine, Height = 2%
683	00:02:30	57.70		BBC A		End > Pos: 5; Settled deposits, fine, Height = 2%
684	00:02:40	60.40		BDA		Pos: 12; General photograph
685	00:02:50	72.10		BDA		Pos: 12; General photograph
686	00:03:00	83.70		BDA		Pos: 12; General photograph
687	00:03:10	89.60		BDA		Pos: 12; General photograph
688	00:03:20	101.30		BDA		Pos: 12; General photograph
689	00:03:30	111.10		BAF A A		Pos: 5; Surface damage, increased roughness, mechanical damage; With bulge
690	00:03:40	111.20		BAF A A		Pos: 7; Surface damage, increased roughness, mechanical damage; With Bulge
691	00:03:50	111.70		BAJ B		Pos: 12- 7; Displaced joint, radial, Distance = 31mm
692	00:04:00	111.70		BAF A A		Beginning > Pos: 1; Surface damage, increased roughness, mechanical damage
693	00:04:10	112.30		BAF A A		End > Pos: 10; Surface damage, increased roughness, mechanical damage
694	00:04:20	112.50		BAJ B		Pos: 4- 8; Displaced joint, radial, Distance = 17mm
695	00:04:30	113.60		BCE A		Finish node, manhole

Section graphics

Section		**Top manhole**	MH011Z 54	**Insp. no.**	147
MH011Z 54 - MH024Z 100		**Bottom manhole**	MH024Z 100	**Insp. date**	06/09/2017
Order number		**Insp. direction**	Down direction of flow		

Videotape	RAK A-202-44	**Sewer no.**	
		Place	RAK -A1-SW-01
Profil	Circular cross-section	**Street**	RAK
Height/Width	250 / 250 mm	**Operator**	ERWIN M.
Pipe length		**Sewer system**	Wastewater
Section length	112,35 m	**Material**	Polyvinyl chloride
Insp. length	113,60 m	**Interr.protec.**	

Scale 1/ 860 **Representation in inspection direction** **Graf. pages** 1

MH011Z 54

Photo	Video	Del./m	Condition	Description
669	00:00:00	0.00	BCDA	Start node type, manhole; Cl.: 1
	00:00:10	0.20	BDDA	Water level, clear effluent, Height = 5%; Cl.: 2
670	00:00:20	0.90	BAJB	Psn: 12 - 6; Displaced joint, radial, Distance = 24mm; Cl.: 4
671	00:00:30	13.80	BDA	Psn: 12; General photograph; Cl.: 1
672	00:00:40	19.70	BDA	Psn: 12; General photograph; Cl.: 1
673	00:00:50	21.50	BAFAA	Psn: 3; Surface damage, increased roughness, mechanical damage; Cl.: 2
674	00:01:00	23.80	BBBB (A)	(1): Psn: 7 - 5; Attached deposits, grease, reduction of cross-section = 2%; Cl.: 2
675	00:01:10	25.20	BBCA (A)	(2): Psn: 6; Settled deposits, fine, Height = 2%; Cl.: 2
676	00:01:20	27.30	BBCA (B)	(2): Psn: 5; Settled deposits, fine, Height = 2%; Cl.: 2
677	00:01:30	27.50	BAFAA	Psn: 8; Surface damage, increased roughness, mechanical damage; Cl.: 2
678	00:01:40	33.60	BBBB (B)	(1): Psn: 0 - 5; Attached deposits, grease, reduction of cross-section = 2%; Cl.: 2
679	00:01:50	34.00	BAFAA	Psn: 3; Surface damage, increased roughness, mechanical damage; Cl.: 2
680	00:02:00	45.20	BBBB (A)	(3): Psn: 7 - 5; Attached deposits, grease, reduction of cross-section = 2%; Cl.: 2
681	00:02:10	51.20	BBBB (B)	(3): Psn: 12 - 5; Attached deposits, grease, reduction of cross-section = 2%; Cl.: 2
682	00:02:20	55.70	BBCA (A)	(4): Psn: 6; Settled deposits, fine, Height = 2%; Cl.: 2
683	00:02:30	57.70	BBCA (B)	(4): Psn: 5; Settled deposits, fine, Height = 2%; Cl.: 2
684	00:02:40	60.40	BDA	Psn: 12; General photograph; Cl.: 1
685	00:02:50	72.10	BDA	Psn: 12; General photograph; Cl.: 1
686	00:03:00	83.70	BDA	Psn: 12; General photograph; Cl.: 1
687	00:03:10	89.60	BDA	Psn: 12; General photograph; Cl.: 1
688	00:03:20	101.30	BDA	Psn: 12; General photograph; Cl.: 1
689	00:03:30	111.10	BAFAA	Psn: 5; Surface damage, increased roughness, mechanical damage; Cl.: 4; With bulge
690	00:03:40	111.20	BAFAA	Psn: 7; Surface damage, increased roughness, mechanical damage; Cl.: 4; With Bulge
691	00:03:50	111.70	BAJB	Psn: 12 - 7; Displaced joint, radial, Distance = 31mm; Cl.: 4
692	00:04:00		BAFAA (A)	(5): Psn: 1; Surface damage, increased roughness, mechanical damage; Cl.: 3
693	00:04:10	112.30	BAFAA (B)	(5): Psn: 10; Surface damage, increased roughness, mechanical damage; Cl.: 3
694	00:04:20	112.50	BAJB	Psn: 4 - 8; Displaced joint, radial, Distance = 17mm; Cl.: 3
695	00:04:30	113.60	BCEA	Finish node, manhole; Cl.: 1

MH024Z 100

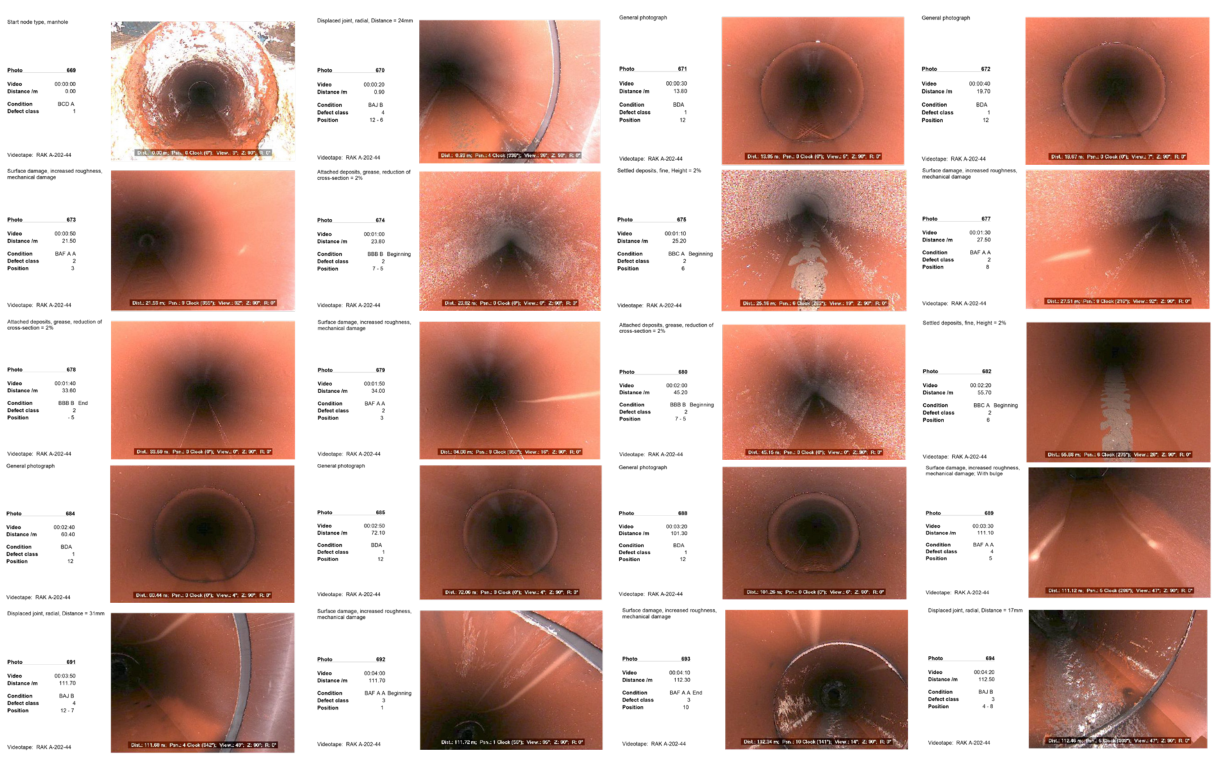


Figure 10. Example FELL Inspection Results Using Electro Scan Inc. Machine-Intelligent Probe

DEFECTS		% OF DEFECT LENGTHS
Small	5	0.00170
Medium	0	0.00000
Large	20	0.02360
All Defects	25	0.02530

LPS SUMMARY	
Minor	0.11
Moderate	1.68
Severe	3.59
Total LPS	5.39
LPD	465,297
LPD IDM	27,230
Minor %	2.10%
Moderate %	31.20%
Severe %	66.71%

DIAMETER & DISTANCE

250

110

0 20 40 60 80 100

OPERATOR INFO

Aramoon Pipe Inspection
Project
West Trunk Main Mairid Network
Job
area 3 inactive wast water network

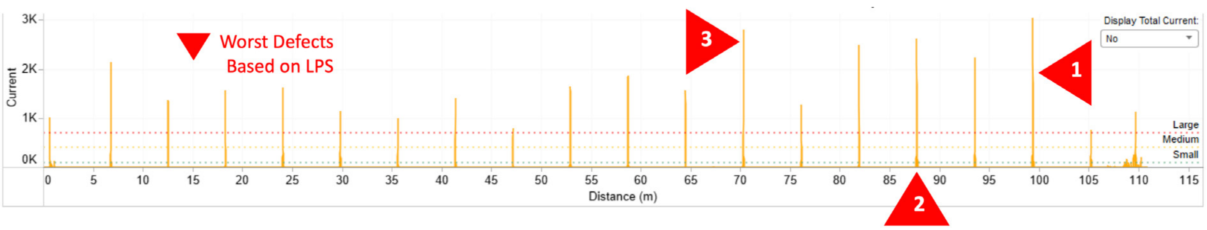
Atmospheric Test	Scan Start
9/21/2017 5:31:37 PM	9/21/2017 7:31:37 PM

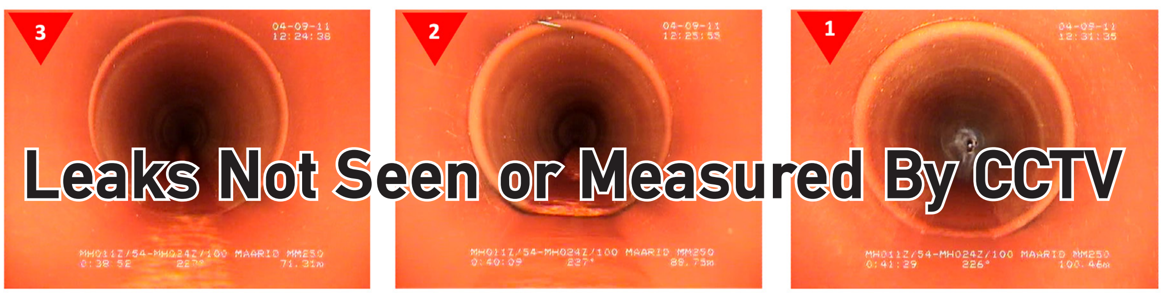
	Defects	Length of Defects ..	LPS	% of LPS	LPD	LPD IDM
Total	25	9,199	5.39	100.0%	465,297	27,230

DEFECT BY LOCATION Mainline ID: MH011Z/54 - MH024Z/100 Pipe ID: MH011Z/54 - MH024Z/100 Diameter: 250 inches Pipe Type: PVC Soil Type: Sand Ground Condition: Dry

Defect Grade	Defect Start	Defect End	Defect Length	LPS	% of LPS	LPD	LPD IDM
L	99,389	99,595	206	0.58	0.11	50,367	2,948
L	87,738	87,960	222	0.53	0.10	45,897	2,686
L	70,326	70,486	160	0.45	0.08	38,811	2,271
L	81,947	82,070	123	0.34	0.06	29,054	1,700
L	93,575	93,698	123	0.32	0.06	28,073	1,643
L	6,795	6,925	130	0.31	0.06	26,383	1,544
L	58,731	58,862	131	0.29	0.05	24,693	1,445
L	24,077	24,230	153	0.27	0.05	23,003	1,346
L	109,700	109,861	161	0.26	0.05	22,131	1,295
L	52,940	53,078	138	0.25	0.05	21,967	1,286
L	[illegible]	[illegible]	[illegible]	[illegible]	0.04	[illegible]	[illegible]
L	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L	29,845	30,006	161	0.22	0.04	18,697	1,094

Worst 9 Defects = 56% of Estimated Defect Flow



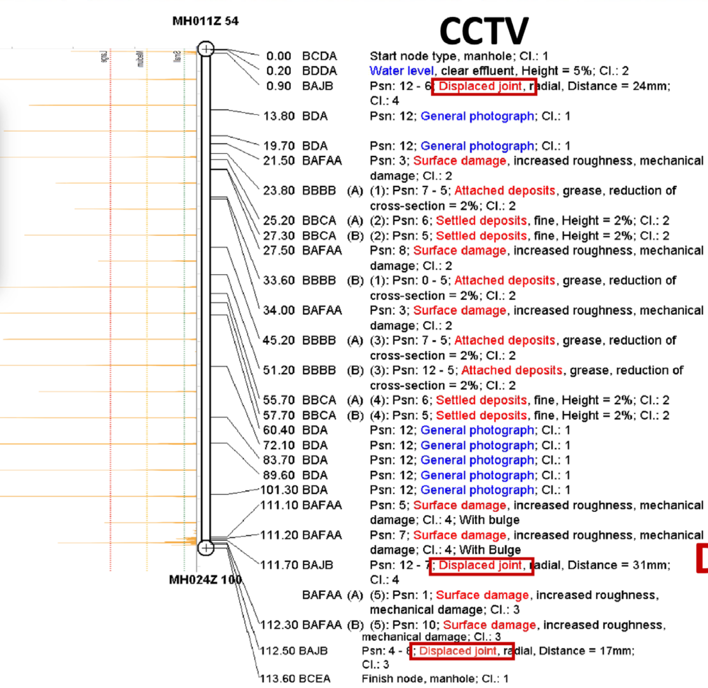


ألكترو سكان **FELL**

Electro Scan

LPS SUMMARY	
Minor LPS	0.11
Moderate LPS	1.68
Severe LPS	3.59
Total LPS	5.39
LPD	465,297
LPD IDM	27,230
Minor LPS %	2.10%
Moderate LPS %	31.20%
Severe LPS %	66.71%

CCTV



25 Total Leaks

FELL Survey Date
21/09/2017

3 Displaced Joints

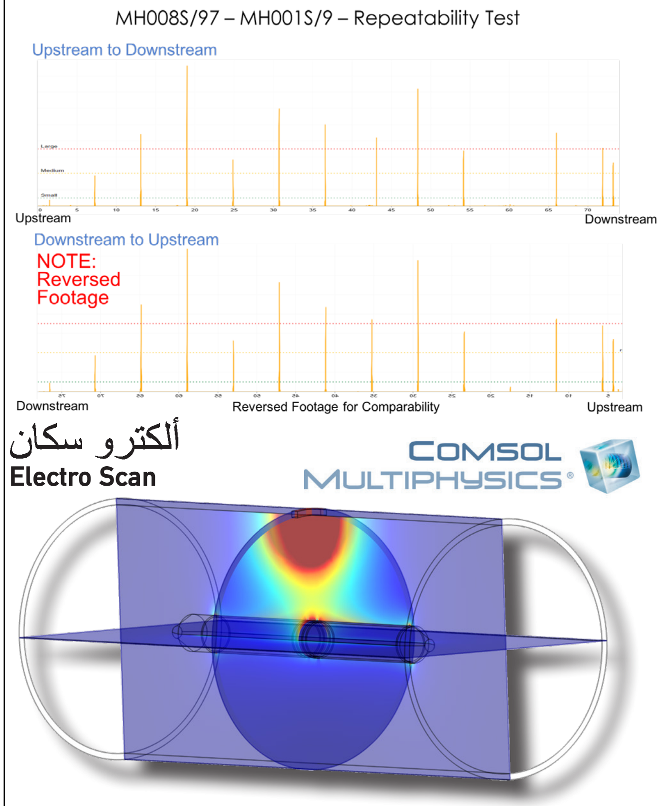
CCTV Date
06/09/2017

FELL REPEATABILITY TESTING

A key advantage of low voltage testing, and reason for adopting FELL watertightness testing, is its ability to replicate survey results, regardless of equipment, software versioning, crew operation, or soil resistivity. As shown in Figure 11, multiple tests were conducted using both forward and backward field testing of the FELL tethered-mounted machine-intelligent probe.

Similar tests had been previously documented by US Environmental Protection Agency (EPA) studies, a Water Environment & Reuse study, and customer benchmarks, including Same-Day Testing conducted by WRc, 60-Day Test Comparisons by the USEPA, and separate agency testing of over 240-days between FELL tests, including different crews, probes, and CCTV cables & reels.

Figure 11. RAKWA FELL Repeatabilty Test



Key benefits of FELL technology, include:

- Unbiased test results, without third-party data interpretation.
- Locational accuracy of 1cm (0.4in)
- Severity of each defect in l/s or gpm.
- Soil type & resistivity agnostic.
- Limited susceptibility to false-positive readings (i.e. unambiguous detection of faults on all non-conductive pipe materials).
- Hydrogeological (i.e. groundwater) independence.
- Works with CCTV cabling, reel, or internal architecture.
- Avg. production rate of 10-15m/min (45-60ft/min).
- Capable of working in diameters from 76mm - 1200mm (3in - 48in).
- Ability to measure Pre- and Post-Rehabilitation Effectiveness immediately after pipe repair or curing.
- COMSOL Multiphysics certification.

Due to poor original construction and acceptance based on visual inspection using CCTV cameras, new standards for water tightness were implemented on all new and rehabilitated pipes.

REHABILITATION SELECTION CRITERIA

Based on results from the condition assessment field surveys, including detailed comparisons of results from CCTV and FELL, RAKWA management directed its consulting engineers to use the following guidelines shown in Figure 12, to plan and execute rehabilitation.

Figure 12. RAKWA Mandated Rehabiitation Selection Criteria

Pipeline Defect or Characteristic	Rehabilitation Selection
FELL Severe Defects (Measured by Liters per Second)	CIPP
Extended 5% Deflection limits of 25% of the length of the line	CIPP
Deflection of more than 10%	CIPP
Open Joints of More Than 20mm	Patch
Leaking Joints	Patch
Intruding Gaskets or Other Material	Cutting & Patch
More Than 4-5 Patches in a Line	CIPP
Low Groundwater	CIPP

Prior to the investigation, an initial rehabilitation budget was to be limited to 375 patches (i.e. sectional point repairs) and 4.5 km of CIPP lining. As a result of FELL testing, rehabilitation was reduced 23% from 4.2km to 3.25km, representing a savings of 1.2M AED. In addition, Patch Repairs were reduced from 373 to 320 patches, representing a savings of 320,000 AED, for a total project savings of 1,520,000 AED. Six months after project completion, ZERO (0) metered flow was measured and confirmed at the associated pump station, indicating 100% reduction in infiltration.

CONCLUSIONS

The days of unlimited capital spending on infrastructure management projects are over, as agencies must use greater care in the prioritisation and selection of capital schemes and measured benefits. Capital efficiency is now a key goal for every new project. In addition to better standards for accepting contractor's new installations, increased standards for watertightness testing must also extend to repairs and rehabilitation as hydrostatic pressure testing of sewer mains and visual optics are insufficient to guarantee workmanship.

Finally, agencies should not fear new technologies, but test results.

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A graduate from the University of Nottingham, with a BEng. and MSc. in Mechanical Engineering, prior to joining RAKWA, Abdul was a design consultant engineer for the health care sector, design engineer for alternative energy, and mechanical design engineer for an oil and gas consultancy in Scotland.