AERODYNAMIC TRAIN FORCE EFFECT TOWARDS THE LINESIDE EQUIPMENT IN THE UNDERGROUND STATION

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ABSTRACT

Transportation always playing an important role in the economic and physical development of modern cities especially rail transportation. Rail transportation is also known as train transport. It is a means of transport, on vehicles which run on tracks. Rail transport is very important, it is commonly used and very cost-effective modes of commuting and goods carriage over long, as well as short distances especially in the high density population cities. The aerodynamic forces around the trains can result in significant pressure loading on lineside equipment especially in the underground station. When a train enters a tunnel, the air ahead of the train nose is compressed and the compression (positive pressure) wave-front propagates through the tunnel at approximately the speed of sound, where it will put pressure to components fixed in the tunnel, whilst later gradually dissipating energy after the train passes by. In this study, the Platform Screen Door (PSD), Emergency Escape Door (EED) and Fixed Panel (FP) are the components that are to be tested to be safe, reliable and rigid enough to withstand the loadings generated from repeating train pressure under different simulated conditions. Pressure sensors were used in this study with several scenario being included in the study by moving the train around the underground tunnel with full speed. The finding of this study shows a very interesting results which will be clearly discussed in this paper. The scenarios show different air pressure profile with both positive and negative pressure of -0.305kPa and 0.345kPa that are safe for the underground lineside equipment.

Keywords: Rail Transportation, Aerodynamic Forces, Air Pressure Profile

INTRODUCTION

An efficient transport system is one that is able to move, as many commuters as possible to their desired destinations, in the shortest possible time. Such was not the experience in the 1960s when the city was plagued with chronic congestion problems in the city center, poor traffic management of its facilities and inefficient public transport operations due to the not well-planned township. Many developing countries had recognized that the lack of an efficient transport system could have a damaging effect on the economic growth and development of the country (Chin & Foong, 2005). With the development of traffic, there are coming more demands for transport such as high speed, efficient work, environmental protection vehicles and transportations.

Transportation is always playing an essential role in the economic and physical development of modern cities. From the days of Malaysian New Economic Policy of 1971, which was to be implemented through a series of four to five year plan from 1971 to 1990, rural poverty did decline particularly in Malayan Peninsula since then with more policies implemented after that (Cavendish, 2007). Malaysia to the present day, the aspiration for an efficient transport system is an evident as a great governance principle among its political leaders. The development of rail transport systems include commuter rail, light rapid transit (LRT), monorail, airport rail link, funicular railway line. Meanwhile, currently Malaysian mass rapid transit (MRT) system is just launched to further cover the transportation system of the greater Kuala Lumpur and some part of Klang Valley region (Corp, 2017).

SURROUNDING IMPACTS FROM THE HIGH SPEED TRAIN

As modern trains travel at higher speed and in lighter weight, resulting them to be more sensitive than ever to wind and surrounding (Chen, et al., 2010). High-speed trains generate transient static pressure changes that impose cyclic loads on surfaces close to the tracks. In the open air, the form of the ‘loading pattern’ (Gilbert, et al., 2013). As the train travels at high speed running into and passing through tunnels and underground station, there will be an apparent and obvious fluctuation of pressure produced in the tunnel and station, which could affect the tunnel surrounding environments and brings safety concerns regarding the equipment and components within the station when the train passes (Luo, 2016).

According to British Standard BS EN 14067-5:2006 stated that any tunnel study longer than 20m should consider using this code of practice (British Standard, 2006). When a train enters a tunnel, the air ahead of the train nose is compressed and the compression (positive pressure) wave-front propagates through the tunnel at approximately the speed of sound, where it will put pressure to components fixed in the tunnel, whilst later gradually dissipating energy after the train passes by. Upon reaching the exit, part of the wave-front energy is reflected as an expansion (suction pressure) wave-front propagating towards the entrance, whilst the rest is emitted out from the exit portal. These reflections continue periodically, whilst frictional losses and portal emissions cause them to decay. This resulting another compression wave is generated when the train nose leaves the tunnel.

Similar phenomenon happens when the train tail enters and leaves the tunnel, expansion waves are generated (Gilbert, et al., 2013).

ISSUES HAPPENED IN UNDERGROUND STATION

A couple of recent tunnel incidents caught the eye(s) of Rail Engineer magazine. There was the episode when permanent way trollies were sucked out of a tunnel recess to land up under a train. Furthermore, there are cases that the underground station platform screen doors had been ripped off 'by a passing train' as in separate incidences. This phenomenon created an interest to the engineers and railway technologist to study on the planning of aerodynamics in a underground railway especially in projects such as high-performance underground or metro systems, high-speed rail tunnels, very long and deep tunnels.

OBJECTIVE

To study the wind load generated by train towards the station's equipment in an underground station.

METHODOLOGY

The aerodynamic forces around the trains (and in particular around the front and back of the trains) can result in significant loading on lineside equipment. These loads are not usually large enough to lead to instant failure, but repeated loading on structures can cause issues of fatigue, with resulting passenger discomfort or unsafe conditions. Aero-Dynamic Train Force Test is one of several aspects of loading tests that are carried out prior to the revenue service. In the methodology of this study, the approach of aerodynamic train force test is used to measure the loading condition generated by the specific train. This aerodynamic force test is carried out in order to demonstrate that the design of the underground lineside equipment, such as the Platform Screen Door (PSD), Emergency Escape Door (EED), Fixed Panel (FP), are safe, reliable and rigid enough to withstand the loadings generated from repeating trains during it's service and meeting the design requirements.

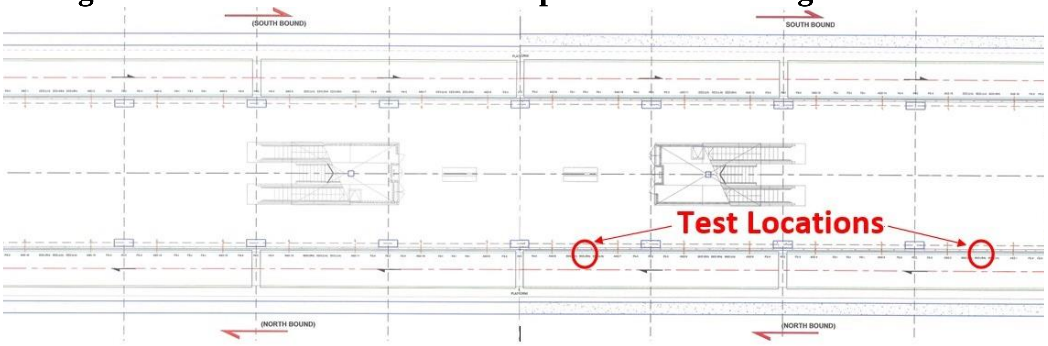
The test location will be at underground station in the Southbound direction. The station selection criterion as follow:

1) No sharp turn before or after station – Safety consideration for 70 kph train
2) Close to opening of tunnel – station close to opening subject to more uncertainties of weather compared to other station

The test points are located at the panels highlighted in Figure 1 below. The sensor will be mounted on the middle of the panels.

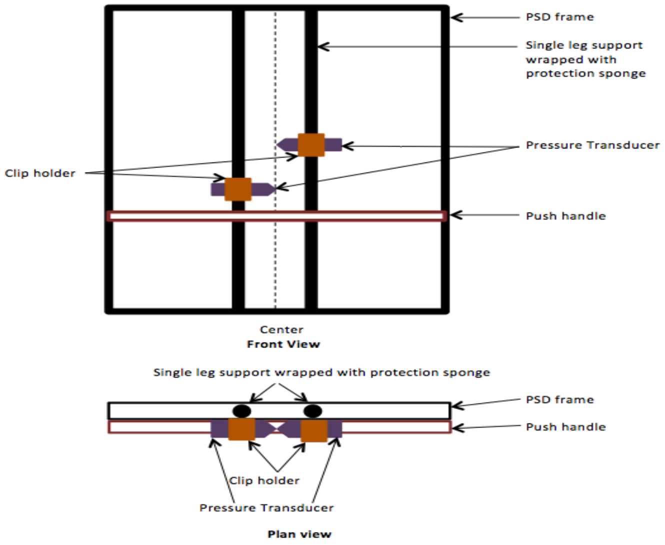
To identify the worst pressure location, there are two measurement locations will be set up along the measuring platform. There are two measurement points, first the measurement point is located at the south end of Station 021 north bound platform, and second measurement point is located in at the middle of Station 021 north bound platform. The sensors in these locations will be able to provide accurate information on the maximum pressure experienced by the panels as the rain passes by the station with maximum velocity.

Figure 1: Location of measurement points at the underground station



Pressure sensors shall be temporary mounted on the center location of the panel. The sensor will sit on a custom-made single leg to support the weight of the sensor. The sensor and custom-made single leg support will be wrapped with protection sponge and stick to the panel's glass using industrial grade heavy-duty tape to position the transducer in place and prevent transducer from any movement. The sensor in each group shall be mounted pointing towards a separate direction, shown in the figure below, to provide a comprehensive coverage for the aero-dynamic force coming from the train.

Figure 2: Pressure sensor mounting mechanism



All four sensors will be connected to a data logger located on the platform. Cables connecting the data logger to the sensor shall run through the gap between the panel frame as shown in the picture below. The cables have a diameter of roughly 3mm. The data logger will be powered by hand carried battery pack. The data logger shall be configured to settings suitable for the measurement at sampling frequency at 5kHz and sensitivity at 50Pa.

Figure 3: Connection of pressure sensor to data logger

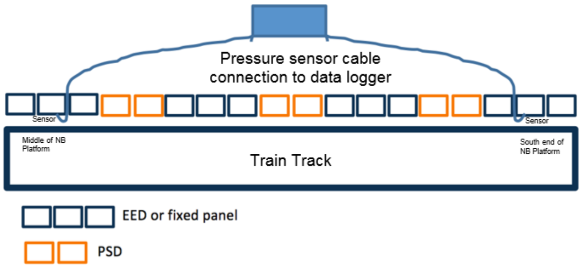


Figure 4: Sensors' location and direction

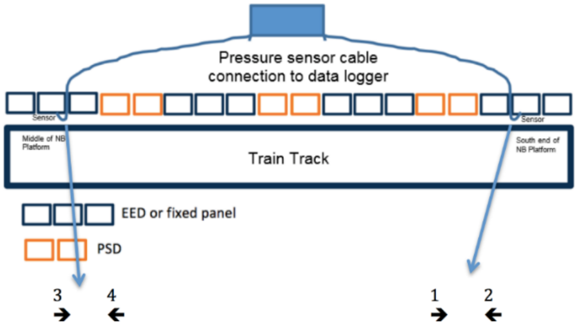


Table 1: Sensors' location and direction

Sensor	Location
1	EED at south end of NB platform
2	EED at south end of NB platform
3	EED at middle of NB platform
4	EED at middle of NB platform

The test will be taken place at the underground station with the following operational scenarios as per mentioned below:

1. Normal operation condition (ie.: piston ventilation effect and trackway ventilation)
2. Tunnel ventilation system (TVS) activated and operating against the direction of traveling train
3. Failure of damper for piston ventilation effect.

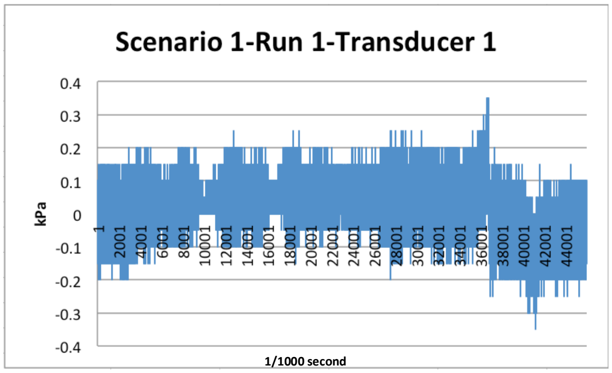
The test loading conditions will be measured and will be compared against the design load conditions to verify that the panels are rigid enough to provide satisfactory operation and integrity performance under all these specified loading conditions. The pressure loading generated by the train on the platform panel shall be below 2.7 kPa, as per the loading capacity of the panel's specification.

DATA COLLECTION AND DISCUSSION

Each scenario was carried out two times and named as Run 1 and Run 2 to ensure the accuracy of data collected. The data logger was configured at a sampling frequency of 1000 Hz. Figure 5 shows data at 1000 Hz, in which there is a total of 46000 data point in 46 seconds of data collection.

SCENARIO 1

Figure 5: Graph plotted using data at 1000Hz



The data was then processed using a mean filter at 100 Hz. This is done to filter the noise caused by vibration of the EED handle and smoothen the graph for better understanding as shown in Figure 6 below.

The graph in Figure 6 illustrates 4 stages of changes in air pressure. The first 36 second shows air pressure built-up when a train approaches the station of the test. The air pressure was at a maximum when the train reached the sensor location. The timing highlighted in red indicated the train is passing the sensor location. The train created a suction force toward the sensor location upon train body leaving the sensor location.

Figure 6: Scenario 1- run 1- transducer 1

Maximum air-pressure = 0.21kPa, Minimum air pressure = -0.215kPa.

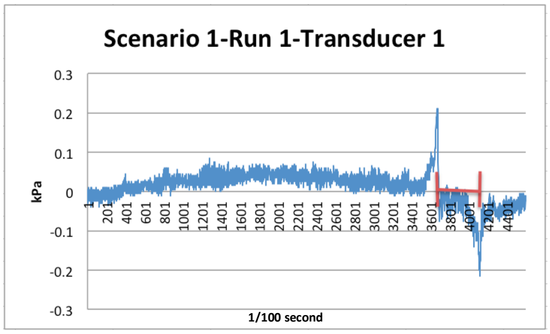


Figure 7: Scenario 1- run 2 – transducer 1

Maximum air-pressure = 0.295kPa, Minimum air pressure = -0.115kPa

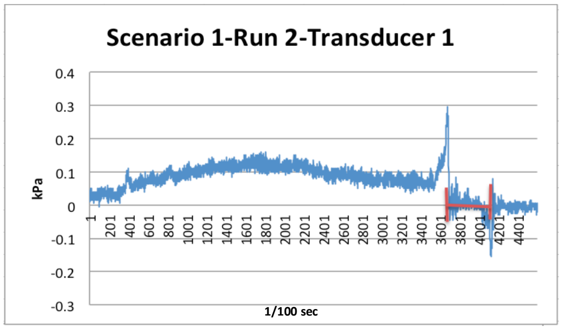


Figure 8: Scenario 1-run 1-transducer 2

Maximum air-pressure = 0.2kPa, Minimum air pressure = -0.205kPa.

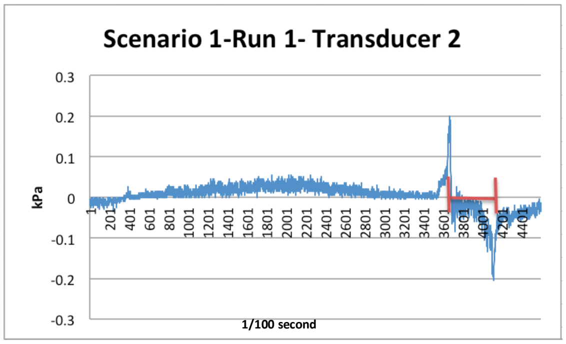


Figure 9: Scenario 1-run 2-transducer 2

Maximum air-pressure = 0.23kPa, Minimum air pressure = -0.195kPa

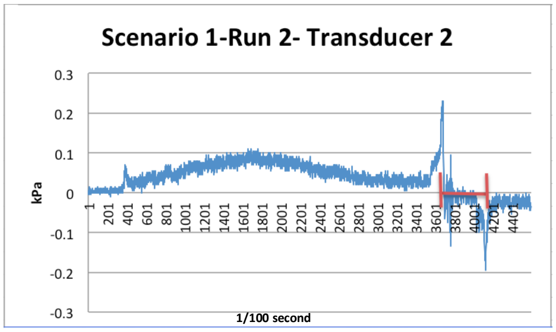


Figure 10: Scenario 1-run 1-transducer 3

Maximum air-pressure = 0.25kPa, Minimum air pressure = -0.205kPa.

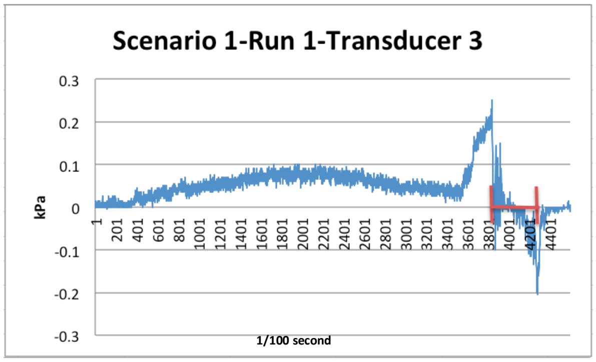


Figure 11: Scenario 1-run 2-transducer 3

Maximum air-pressure = 0.33kPa, Minimum air pressure = -0.105kPa.

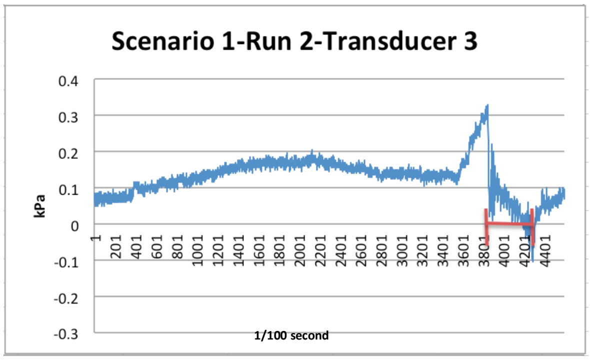


Figure 12: Scenario 1-run 1-transducer 4

Maximum air-pressure = 0.21kPa, Minimum air pressure = -0.215kPa.

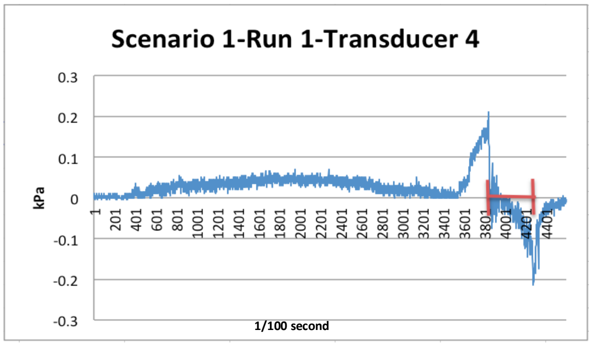
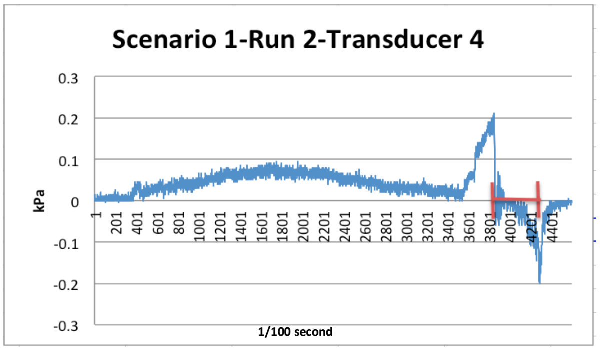


Figure 13: Scenario 1-run 2-transducer 4

Maximum air-pressure = 0.21kPa, Minimum air pressure = -0.2kPa.



In the scenario 1, test train was routed from Station-03 (NB) to Station-01 (NB) and bypass Station-02 at maximum velocity. Measurements obtained from the air pressure sensors, located at the middle and south end of Station-02 (NB) platform, as the train passes by.

The ventilation for this scenario set in Normal Operation condition for train service (i.e. Piston Ventilation effect with Trackway Ventilation).

For Scenario 1, all 4 sensors pick up similar air pressure profile. For the first 36 second, the air pressure built up and decreased due to the changes of train speed. Train is moving at 95kmph in the tunnel and decrease to 75kmph before reaches the station.

The air pressure hit maximum when the train reaches sensor location. The timing highlighted in red indicated the train is passing the sensor location. The train created a suction force toward the sensor location upon train body leaving the sensor location. The maximum air pressure recorded in Scenario 1 is 0.33kPa and minimum is -0.215kPa. The few second after the train passes the sensor, there is fluctuation on the graph and it has more fluctuation on the red colour H marked, because the vibration created by the movement of the train.

SCENARIO 2

In this scenario, test train was routed from Station-03 (NB) to Station-01 (NB) and bypass Station-02 at maximum velocity.

The Tunnel Ventilation System (TVS) for this scenario was activated operating against the train travel direction.

Figure 14: Scenario 2-run 1-transducer 1

Maximum air-pressure = 0.285kPa, Minimum air pressure = -0.185kPa.

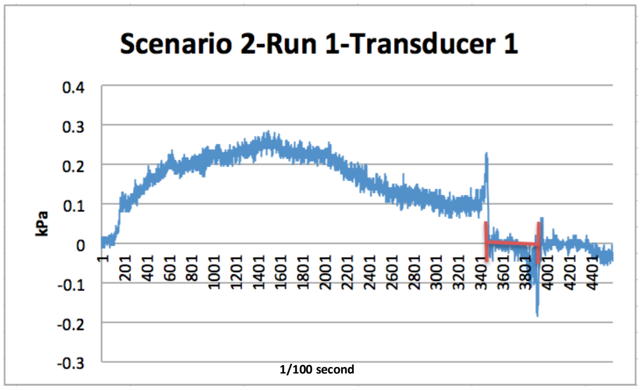


Figure 15: Scenario 2-run 2-transducer 1

Maximum air-pressure = 0.345kPa, Minimum air pressure = -0.12kPa.

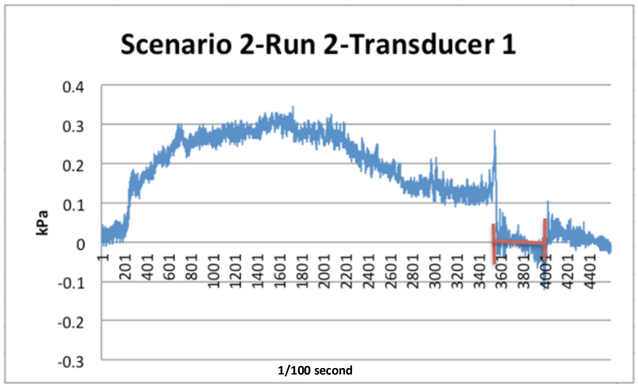


Figure 16: Scenario 2-run 1-transducer 2

Maximum air-pressure = 0.27kPa, Minimum air pressure = -0.16kPa

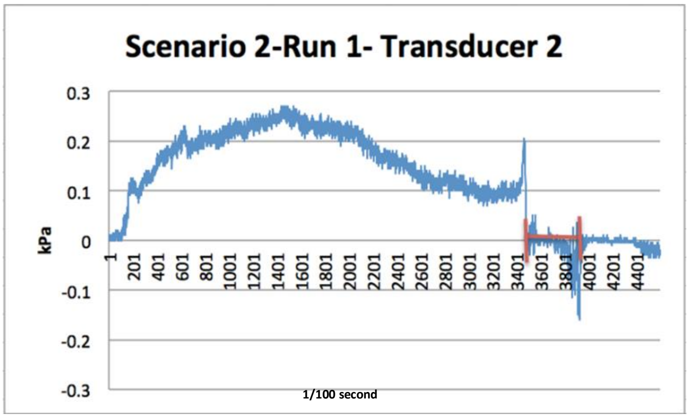


Figure 17: Scenario 2-run 2-transducer 2

Maximum air-pressure = 0.32kPa, Minimum air pressure = -0.125kPa.

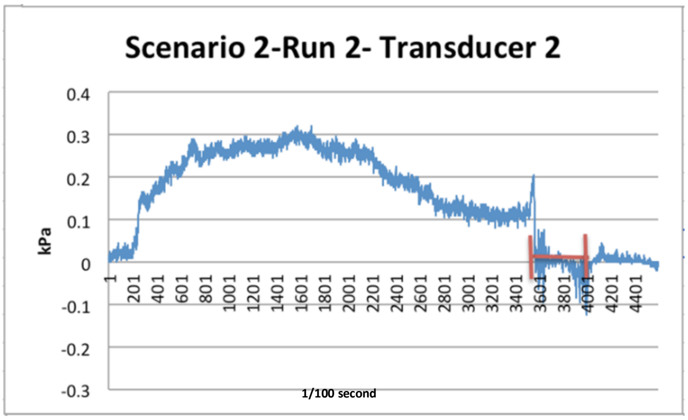


Figure 18: Scenario 2-run 1-transducer 3

Maximum air-pressure = 0.285kPa, Minimum air pressure = -0.2kPa.

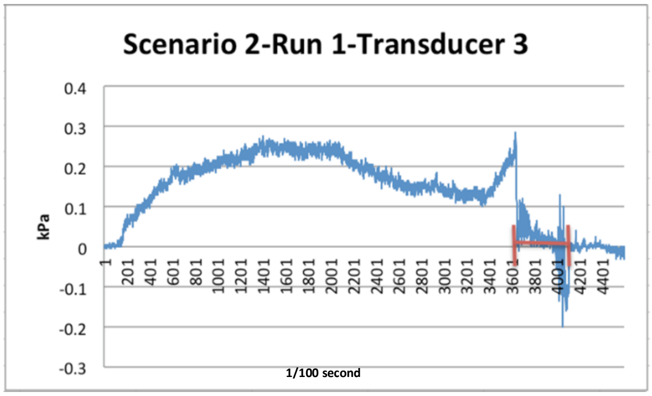


Figure 19: Scenario 2-run 2-transducer 3

Maximum air-pressure = 0.34kPa, Minimum air pressure = -0.11kPa.

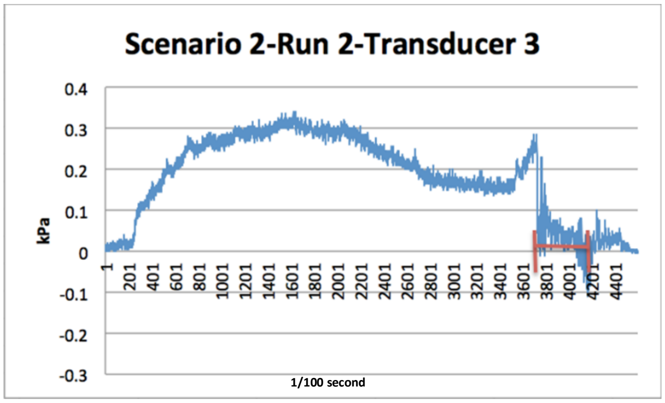


Figure 20: Scenario 2-run 1-transducer 4

Maximum air-pressure = 0.215kPa, Minimum air pressure = -0.25kPa.

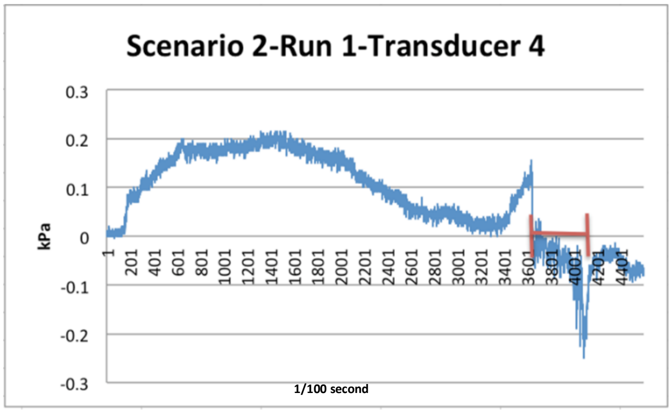
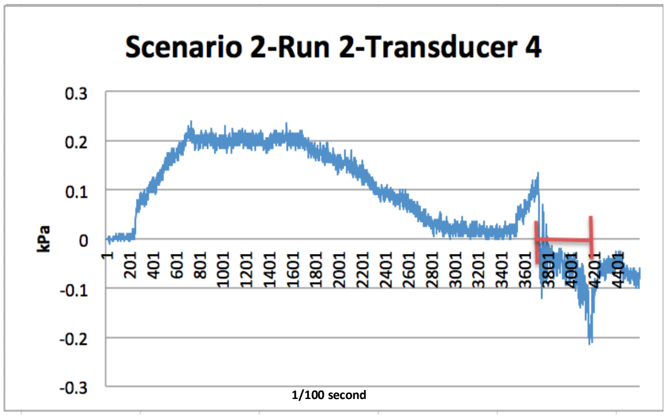


Figure 21: Scenario 2-run 2-transducer 4

Maximum air-pressure = 0.24kPa, Minimum air pressure = -0.215kPa.



Tunnel Ventilation System (TVS) was activated operating against the direction of the travelling train. Pressure sensor recorded a built up in pressure as the train approaches the station of measurement. The maximum air pressure recorded as the train approaches the station was higher than the moment train reaches the sensor location. The maximum and minimum air pressure recorded throughout Scenario 2 on both runs are 0.345kPA and -0.25kPa respectively.

SCENARIO 3

Test Train #1 (TT1) routed from Station-03 P2 (NB) to Station-01 P2 (NB) and bypass Station-02 at maximum velocity.

The Tunnel Ventilation System (TVS) for the Piston Ventilation Effect Damper located at the south end of Station-02 was set to close. This was to simulate a piston effect on damper failure scenario for the tunnel in station Station-02.

Figure 22: Scenario 1-run 1-transducer 1

Maximum air-pressure = 0.165kPa, Minimum air pressure = -0.295kPa.

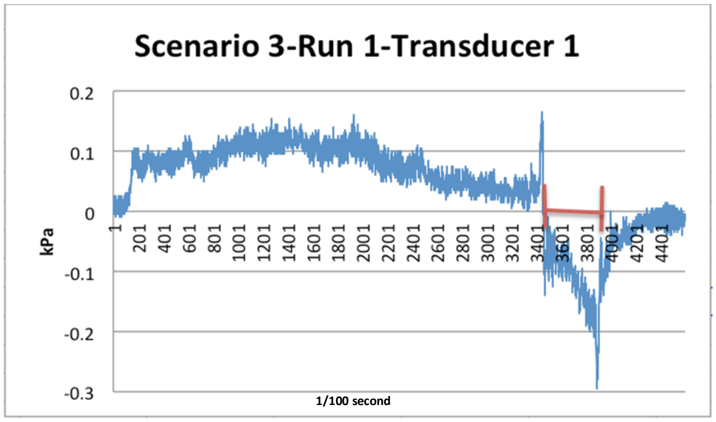


Figure 23: Scenario 3-run 2-transducer 1

Maximum air-pressure = 0.165kPa, Minimum air pressure = -0.305kPa.

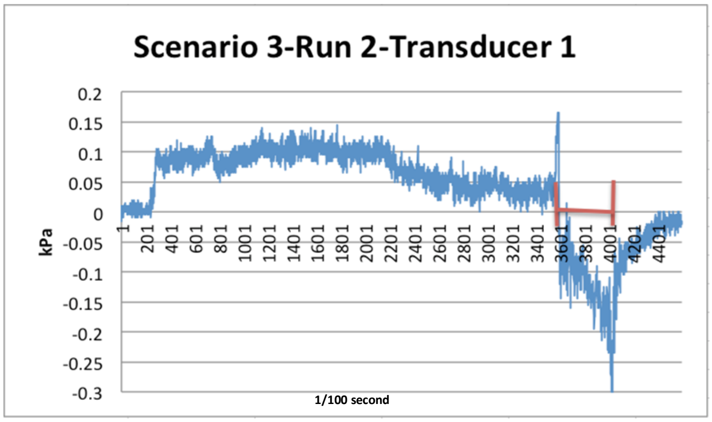


Figure 24: Scenario 3-run 1-transducer 2

Maximum air-pressure = 0.12kPa, Minimum air pressure = -0.275kPa

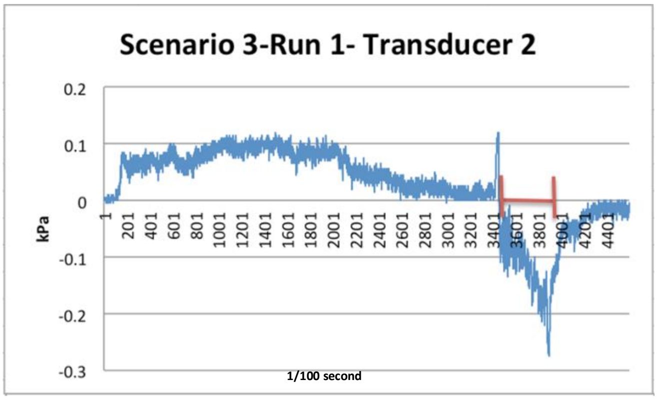


Figure 25: Scenario 3-run 2-transducer 2

Maximum air-pressure = 0.135kPa, Minimum air pressure = -0.3kPa.

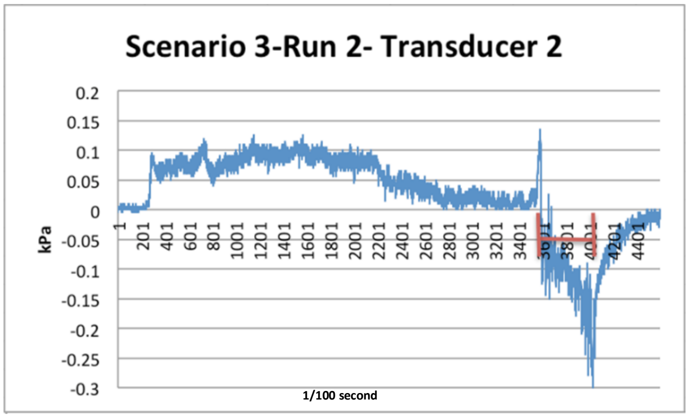


Figure 26: Scenario 3-run 1-transducer 3

Maximum air-pressure = 0.2kPa, Minimum air pressure = -0.205kPa.

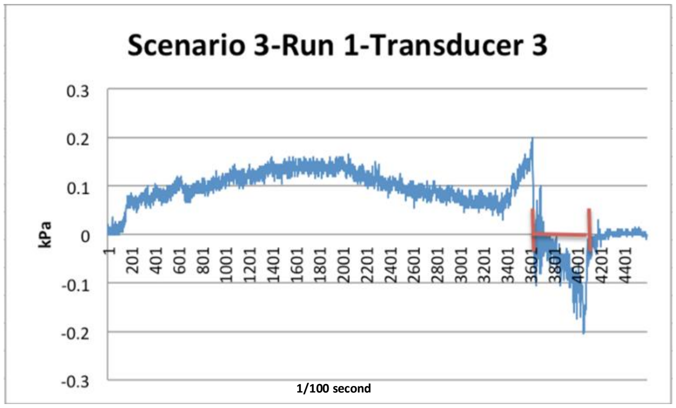


Figure 27: Scenario 3-run 2-transducer 3
Maximum air-pressure = 0.225kPa, Minimum air pressure = -0.2kPa.

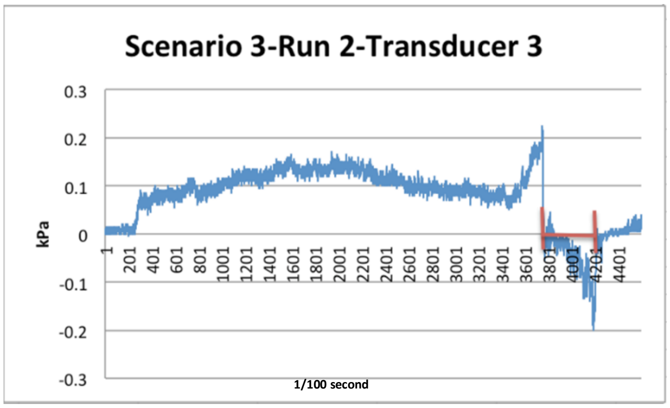


Figure 28: Scenario 3-run 1-transducer 4
Maximum air-pressure = 0.11kPa, Minimum air pressure = -0.255kPa.

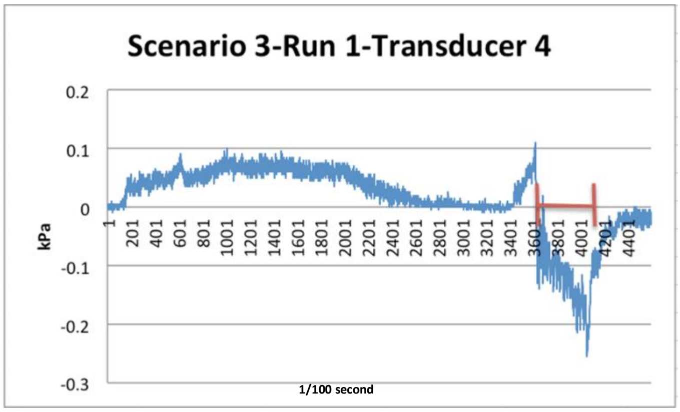
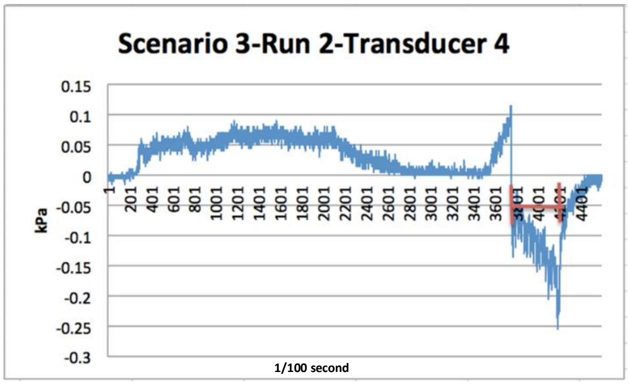


Figure 29: Scenario 3-run 2-transducer 4
Maximum air-pressure = 0.115kPa, Minimum air pressure = -0.255kPa.



It is observed that the air pressure profile for Scenario 3 is different from Scenario 1 and Scenario 2. The closed damper caused a higher built up in air pressure as the train approaches the station as compared to Scenario 1. The suction force generated when the train leaves the sensor was much larger compared to both Scenario 1 and 2. The maximum and minimum air pressures recorded throughout Scenario 3 on both runs are 0.225kPA and -0.305 kPa respectively.

CONCLUSION

All three scenarios show a different air pressure profile. For Scenario 1, the recorded air pressure built up as the train approaches the station of measurement was not as high as the other two scenarios. The maximum pressure was recorded when the train reaches the sensor location and minimum pressure was achieved when the train leaves the sensor.

For Scenario 2, the impact of TVS operating against the direction of traveling train resulted in a rapid built up of air pressure as the train approaches the station of measurement the duration of having high pressure is longer than other two scenarios.

As for Scenario 3, the damper was closed to simulate piston effect during damper failure. The data shown a built up of air pressure as the test train approaches the station of measurement and the recorded air pressure was higher than Scenario 1 but lower than Scenario 2. Another observation is, when the train leaves the sensor location, the negative air pressure generated is higher than the other two scenarios.

All-inclusive, the maximum-recorded air pressure is 0.345kPa, and the minimum is -0.305kPa for all three scenarios.

This test shows the design of the lineside equipment (i.e. PSD and EED) can withstand repeated train generated loading conditions due to Aero-dynamic Train Forces in the underground section as per consultant engineer’s design requirements of 2.7+- kPa and safe for servicing passengers in the underground station.

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