Eisenhower / Johnson Memorial Tunnel Electrical Inspection Report

Volume I

Prepared for
Colorado Department of Transportation
Region 1
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By

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EXECUTIVE SUMMARY

Parsons Brinckerhoff was engaged by the Colorado Department of Transportation (CDOT) to evaluate the existing electrical system, including the ventilation fan motors, at the Eisenhower/Johnson Tunnel, and then make recommendations relative to replacement, upgrade, or continued use of existing systems or equipment.

The evaluation included a physical inspection of the system electrical equipment and fan motors, as well as the actual electrical and other testing of the major electrical equipment, such as power transformers, switchgear, relays and fan motors.

The physical inspection, which took place on December 15, 2004, and March 22nd -23rd of 2005, did not unearth any significant deficiencies. The actual testing, however, which took place between March and August of 2005, did discover some problems, primarily with the 460V switchgear and protective relays. The testing also indicated that although failure was not imminent, some of the fan motors should be investigated more closely.

The recommendations include the following:

Commission a comprehensive short circuit and coordination study for the entire electrical system.

Commission a comprehensive study of the emergency power system.

Institute regular maintenance testing program.

Replace the 460V switchboards at both portal buildings, at an approximate cost of $3,100,000.

Replace 24.9kV service at the West portal building, and the tie circuit between the two buildings (through the tunnel), at an approximate cost of $490,000.

Check bearings and alignment of fan motor EE-5 to determine cause of vibration.

Re-test 17 fan motors in approximately 4-6 months, to ascertain trend of insulation resistance of indicated fan motors.

Check with generator supplier/manufacturer to determine if adjustments can be made to prevent generator from tripping at loads approaching full capacity.

Paint tops of step-voltage regulators.

Keep tie cable energized at all times.

Operate each fan motor for approximately four hours, every 1-2 months.

1.0 BACKGROUND

The Eisenhower/Johnson Memorial Tunnel is located approximately sixty miles west of Denver, Colorado on Interstate Route 70.

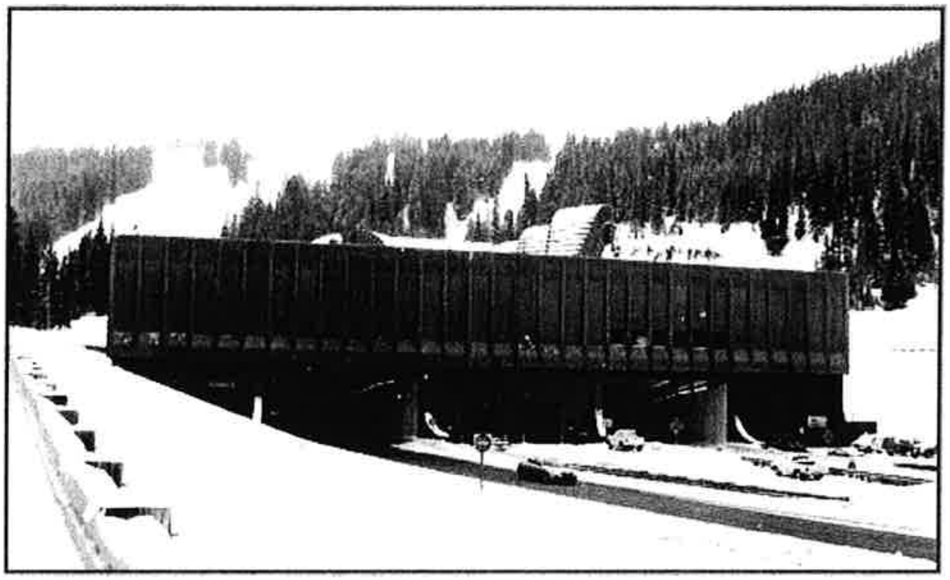


Photo 1—East Portal and Portal Building

Construction on the westbound bore, also known as the North Tunnel, was completed in early 1973, while for the eastbound bore, also known as the South Tunnel, construction was completed in late 1979.

The westbound bore (North Tunnel) was named after President Dwight G. Eisenhower and the eastbound bore (South Tunnel) after Edwin C. Johnson, a past Colorado Governor and U.S. Senator, who had actively supported an interstate highway system across Colorado.

The length of the westbound bore is 8,940 feet, and of the eastbound bore, is 8,960 feet.

The tunnel is staffed 24 hours/day, 365 days/year, utilizing 52 full-time employees.

As can be seen, the North Tunnel is over 32 years old, and the South Tunnel is approaching 26 years old. During the six year span between completion dates, the electrical design of the South Tunnel was modified somewhat from that of the North Tunnel, primarily, changing the driving voltage of the ventilation fan motors from the North Tunnel's 460V, to 2.4kV for the South Tunnel.

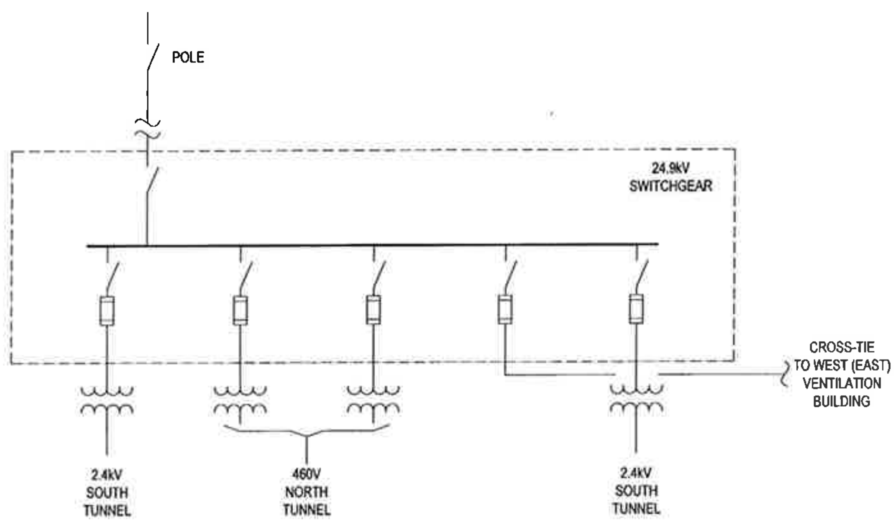
In essence, the electrical systems and ventilation fan motors for the Eisenhower/Johnson Memorial Tunnel are approximately 30 years old. This is evidencing itself in burnt-out fan motors and similar problems in the electrical systems. The 24 hour/day, 365 days/year operation of the tunnel dictates that the necessary electrical power to maintain the maximum ventilation level in the tunnel be available at all times. To this end, CDOT has commissioned this report, the prime task of which is to evaluate the electrical system and the fan motors at the Eisenhower/Johnson Tunnel.

2.0 ELECTRICAL SYSTEM DESCRIPTION

2.1 24.9kV System

The design of the existing electrical system exhibits a relatively high degree of redundancy. The approximately 8,950 ft. tunnel has a ventilation building/substation located at either end. Each substation is supplied from a different 14.4/24.9kV, solidly grounded, wye circuit from Xcel Energy. In addition, an emergency tie circuit, routed through the North Tunnel, has the capacity to supply either substation from the other, in the event either of the primary sources is lost. The primary circuits at either end are routed through step-voltage regulators to maintain a constant input voltage to each substation. The substations at either end of the tunnel are essentially identical electrically, as described below.

The 24.9kV primary incoming circuit is terminated at a bus within 600A, 34.5kV, indoor, metal enclosed switchgear. Also terminated at this bus is the emergency tie circuit. All connections to the bus are via electrically operated switches, and utilize fuses for protection. See simplified one-line diagram below:

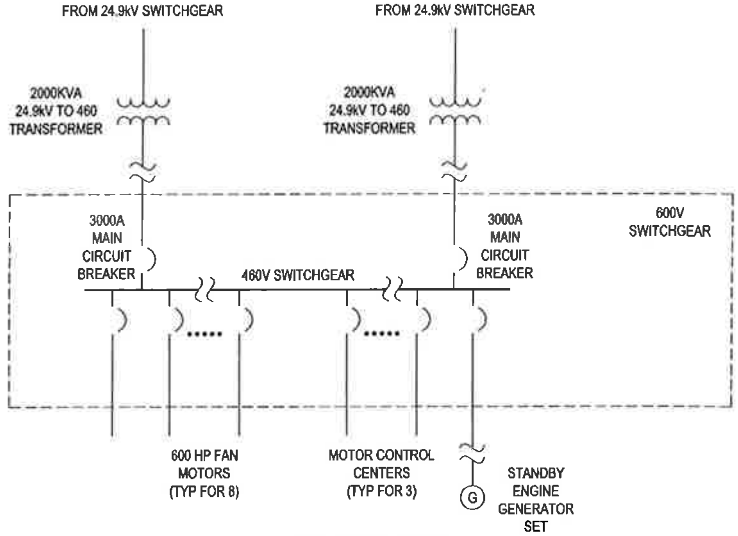


24.9kV POWER SYSTEM
EAST VENTILATION BUILDING SHOWN
WEST VENTILATION BUILDING SIMILAR

2.2 North Tunnel

The North Tunnel fans are powered from the primary switchgear through each of 2- 2000kVA, 24.9kV/460V liquid-filled transformers at each ventilation building. The transformers, in turn, supply 600V metal-enclosed, 3000A, drawout switchgear, via 3000A main breakers, with no tie breaker. There is no tie circuit breaker provided because at the time of the design of the power system for the North Tunnel, which was the first of the two tunnels to be constructed, it was planned that the switchgear for the then future South Tunnel would be added onto the existing line-up for the North Tunnel. At that time, one of the two main circuit breakers in each of the North Tunnel switchgear line-ups would become the tie circuit breaker between the two halves of the expanded switchgear line-ups.

In normal operation, only one main circuit breaker is closed. If that feeder is lost, manual transfer is required to transfer to the other main circuit breaker. The 3000A bus supplies the various Motor Control Centers (MCC's) which serve the building and tunnel lighting, traffic control, North Tunnel fan motors (and South Tunnel Fan Damper Motors), etc. A 500 kW (625kVA) generator is also connected to this bus to serve essential building and tunnel loads in the event of total loss of utility power to this (these) bus(es). See simplified one-line diagram below:

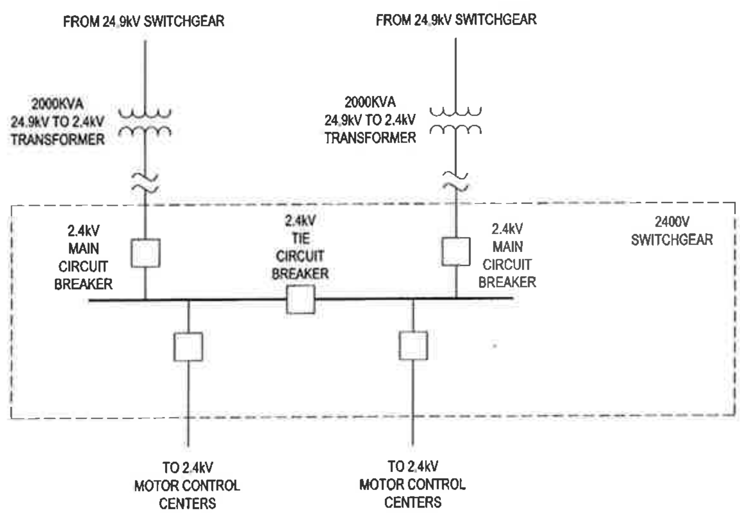


460V POWER SYSTEM
TYPICAL FOR EACH VENTILATION BUILDING

2.3 South Tunnel

The South Tunnel fans are also powered from the primary switchgear, similar to the North Tunnel, through each of 2-2000kVA, liquid-filled transformers at each ventilation building, but in this case, the voltage ratings are 24.9kV to 2.4kV, rather than 24.9kV to 460V. These transformers supply a double ended power center with a three-switch scheme, i.e. main-tie-main. The bus is tapped between the tie and main breakers to supply two single-ended motor control centers, which supply the tunnel fans for the South Tunnel, as well as feeders for tunnel transformers.

A point worth noting is that whereas the 460V MCC's employ draw-out circuit breakers for fan feeder protection, the 2.4kV MCC's utilize draw-out fuses instead. See simplified one-line diagram below:



2.4kV POWER SYSTEM
TYPICAL FOR EACH VENTILATION BUILDING

3.0 VENTILATION FAN MOTORS

As indicated in the previous section, the fan motors for the North Tunnel are supplied from a 460V system, while those for the South Tunnel are supplied from a 2.4kV system.

3.1 460V Motors

Not counting damper motors, etc., the North Tunnel fans are driven by 16 dual speed/dual horsepower (12.5/100HP) motors in conjunction with 16 single speed/single horsepower (600HP) motors (essentially, 16 three speed motors).

3.2 2.4kV Switchgear

The newer South Tunnel fans, in addition to operating at 2400V instead of 460V, are driven by 24 dual speed/dual horsepower motors in "pairs" of 2 (25/200HP and 100/600HP), i.e., 12 fans driven by 2 dual speed/dual horsepower motors (essentially, 12 four speed motors).

4.0 INSPECTION AND TEST RESULTS

4.1 Inspection

The site was visited by Alfred Pizzano, Jr., and Jeffrey P. Sheldon, both of Parsons Brinckerhoff, on December 15, 2004 and also on March 22nd and 23rd of 2005. Photographs were taken and observations noted on both occasions. Except for a more detailed look at the incoming 24.9kV while within the East Ventilation Building, (explained below), the physical inspection of the equipment enumerated in Sections 2.0 and 3.0 did not unearth anything suspect (see following photographs).

Relative to the incoming 24.9kV cubicle, panels were removed by CDOT personnel to allow a somewhat restricted view of the interior (line was still energized). This was shortly after a lightning storm had damaged an insulator at the switchgear cubicle, and emergency repairs had been made. What little could be seen (see photographs below) , indicated that a fair amount of work would be required to bring this cubicle back to standard construction

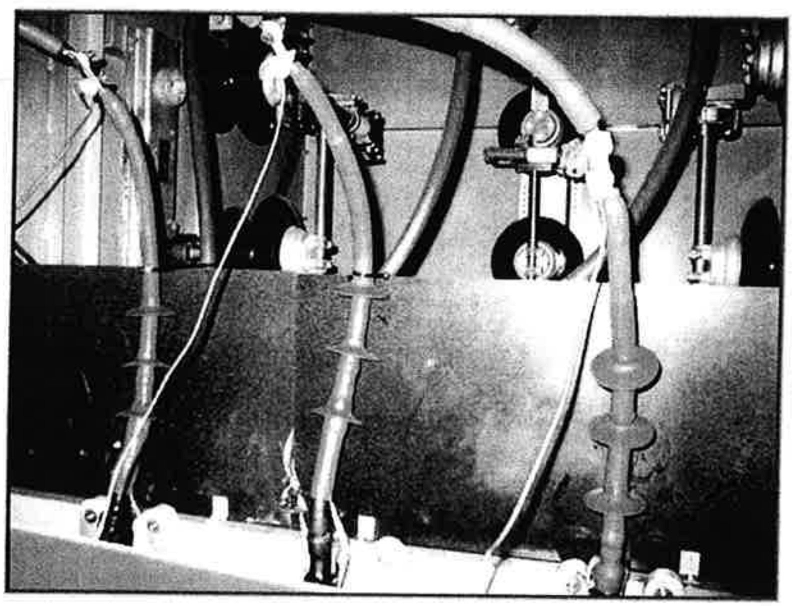


Photo 2—Incoming 24.9kV Line Showing Connection to Regulator Line Side Feeder Conductors. Note That Connection to Feeder Conductors Is Unsupported

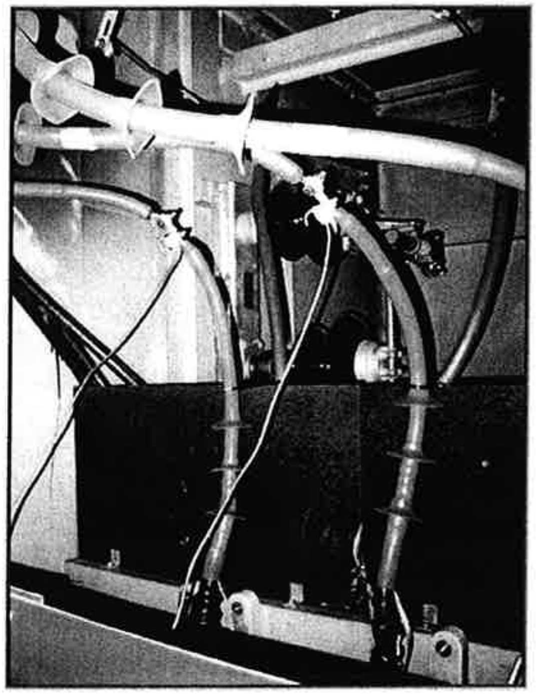


Photo 3—Another View of 24.9kV Incoming Conductors

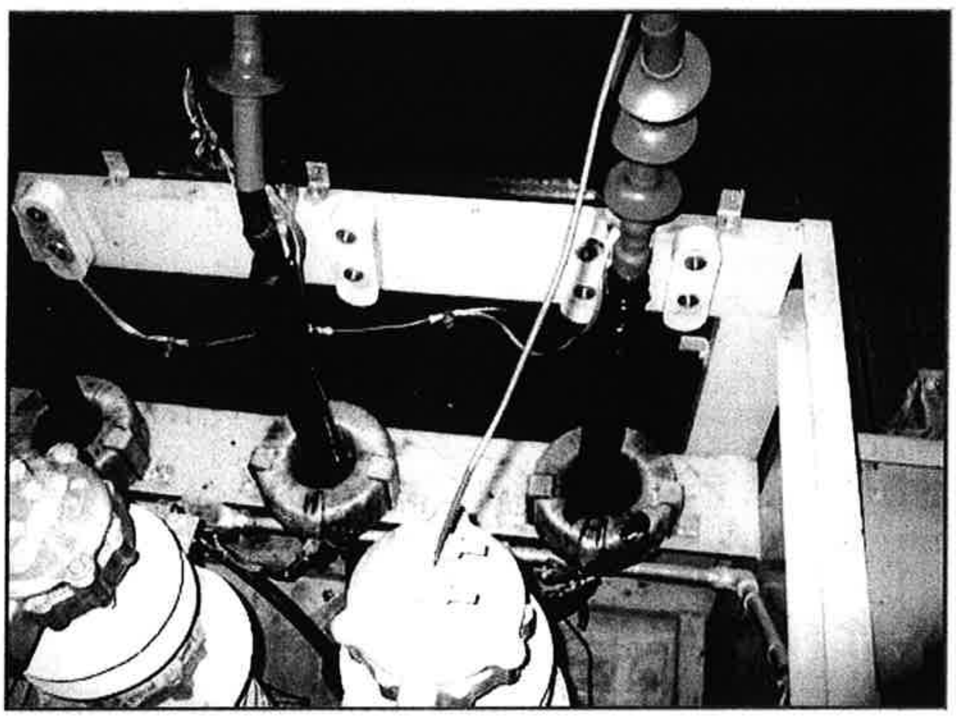


Photo 4—Incoming 24.9kV Conductors Showing Current Transformers and Lightning Arresters in Foreground

4.2 Test Results

Other than for the incoming 24.9kV cubicle mentioned above, the results of the Electrical Testing of the Electrical System and Ventilation Fan Motors, tell a different story than the physical inspection. Everything that follows in this section should be qualified by the fact that the original electrical systems and fan motors for the North Tunnel were installed approximately 32 years ago, and 26 years ago for the South Tunnel equipment. Also, the testing results are essentially summarized in this section. Details can be found in Appendix 2.

The discussion will begin with that equipment which was tested, followed by that equipment which was not tested, and the reason thereof.

4.2.1 Transformers

All eight power transformers, four rated at 2000kVA - 24.9kV/460V, and four rated at 2000kVA - 24.9/2.4kV, were tested for insulation resistance and turns ratio, and Doble tested for insulation power factor. Their insulating fluid was laboratory tested for dielectric strength, interfacial tension, acid content, moisture content, viscosity, specific gravity, color number, and visual condition. All transformer test values were within the acceptable range for transformers of this type.

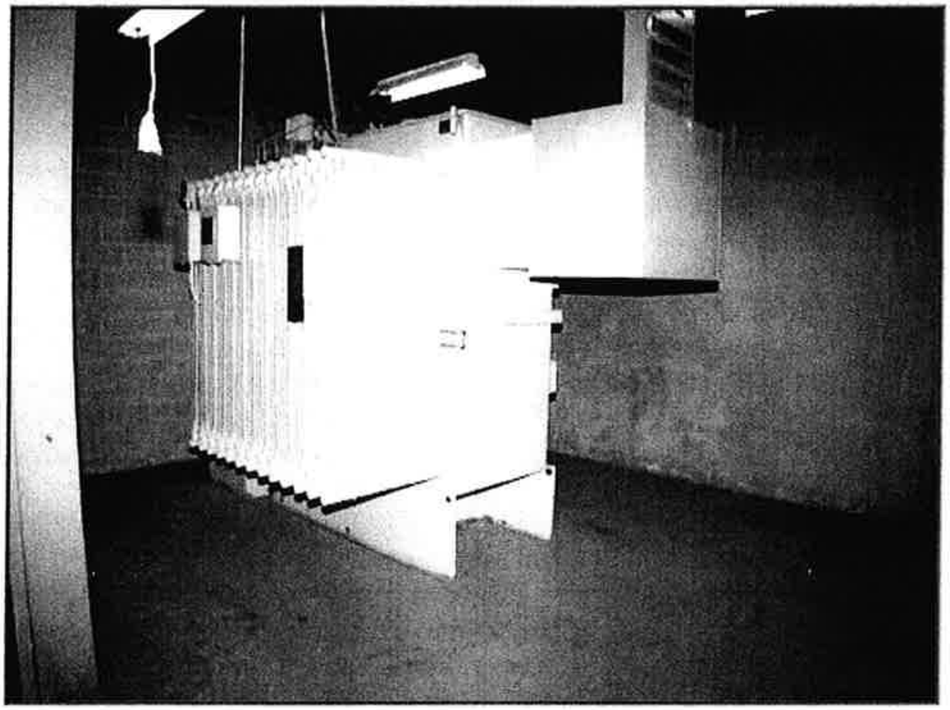


Photo 5—Typical 24.9kV to 480/277V Transformer

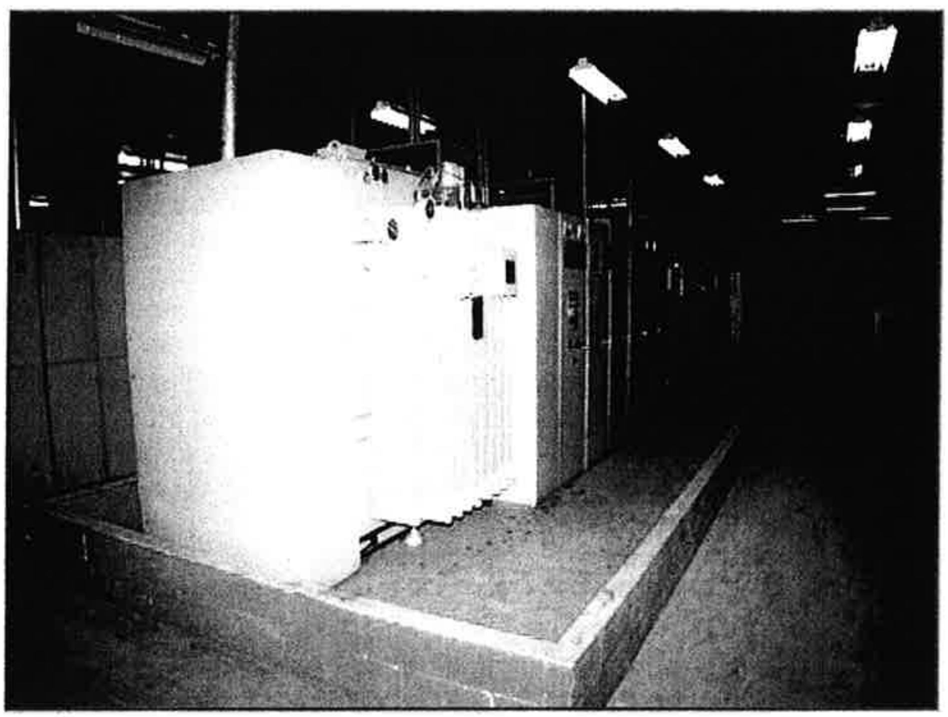


Photo 6—Typical 24.9kV to 2.4kV Transformer

4.2.2 Fan Motors

The fan motors are of basically four types; dual speed 12.5/100HP @460V, single speed 600HP @ 460V, dual speed 25/200HP @ 2.4kV, and dual speed 100/600HP @ 2.4kV. Surge comparison testing was performed on all motors. The resulting wave form photograph of each, did not indicate any trouble.

All motors were tested for vibration at all speeds. The horizontal and vertical vibrations at the drive end, and, where safely accessible, the horizontal, vertical and axial vibrations at the far end, were measured and recorded. The four acknowledged ranges for vibration are Good, Acceptable, Tolerable and Defective, which are self explanatory.

All sixteen 12.5/100HP, 460V, motors were rated Good. Of the sixteen 600HP, 460V motors, two were rated Good, twelve were rated Acceptable, and the remaining two (WE-3 and WE-4) would not start at time of test. Follow-up discussions indicated that the failure to start was attributed to control malfunction, which has been corrected.

All twelve of the 25/200HP, 2.4kV motors were rated Good. Of the twelve 100/600HP, 2.4 kV motors, the 600HP portion of EE-5 was rated just Tolerable, and the remainder were rated Good, except for the 600HP portions of WS-5 and WS-6, which would not start at time of test. Follow-up discussions indicated that the failure to start was attributed to control malfunction, which has been corrected.

Every motor was subjected to insulation resistance testing including calculation of the Polarization Index and the Dielectric Absorption Ratio. By voltage and size class, the results showed 6-12.5HP, 4-100HP and 3-600HP motors, all at 460V, and 4-25HP and 6-200HP motors, all at 2.4kV had insulation resistance readings that were suspect. This does not mean that failure of these motors is imminent, but, all of these motors should be re-tested in six months to determine the rate of deterioration of the insulation. The 2.4kV, 100/600HP units all exhibited proper insulation resistance.

4.2.3 460V Switchgear

The North Tunnel ventilation fans are supplied from the 460V switchgear, either directly, as are the 16-600HP motors, or indirectly from 460V Motor Control Centers (MCC's) which are supplied from the switchgear, as are the 16-12.5/100HP motors. The switchgear is manufactured by General Electric Co. and employs G.E.'s type AK-50 and AK-75 drawout circuit breakers.

Multiple issues arose with this equipment. All feeder breakers have been retrofitted with current limiting fuses, allowing a higher short circuit current to be interrupted than if they were not installed. The two main breakers, however, did not have current limiting fuses installed. Further, no information could be found relative to the design short circuit capability of the gear itself, i.e., maximum level of short circuit current that the unit can safely handle on its buses with the original bus bracing.

It was very difficult to remove and reinstall the drawout breakers, both from and to their cells, due to the cell racking mechanisms being in poor to very poor condition. This condition might have been exacerbated due to the addition of the retrofitted current limiting fuses, which do add weight and change the center of gravity of the circuit breakers.

Mechanically, in addition to the racking problem, it was found that the spring charging gear case of all the AK breakers were leaking oil. In addition, all circuit breakers were found to be very dirty. The fixed and moveable contacts, intermediate contacts, and arcing contacts were cleaned as best as possible, but they are still in need of an extensive detailed cleaning. The lubrication of the circuit breakers was either non-existent, dry, contaminated or gummed-up. The best way to correct the above deficiencies is to have the circuit breakers sent to a shop facility for disassembly, cleaning and lubrication.

In addition to the preceding, the series over-current trip units for ten of the circuit breakers at the East Portal, and two at the West Portal, are no longer operating within the manufacturer's published time-current curves.

Photo 7—480V Switchgear

4.2.4 2.4kV Switchgear

The South Tunnel fans are supplied from the 2.4kV power center, which consists of 3 – 2.4kV circuit breakers in a main-tie-main configuration, which in turn supplies two motor control centers, each of which utilizes drawout fuses instead of circuit breakers. Although it was reported that the 2.4kV breakers were very dirty, they passed all applicable tests.

4.2.5 Protective Relays

The protective relays for the electrical system were found to not be in the best of condition. Some of the problems encountered included defective jewel bearings on the time disk, broken covers, dirt in the air gap preventing movement of disk and missing setting scales. Many of the relays were at the maximum adjustment end of the time dial drag magnet, forcing the time dial setting to be used to bring the relay time dial into calibration. Other relays required adjusting the time dial return stop to bring them into calibration. These measures render the time dial graduations no longer valid, thus requiring re-calibration for any setting changes. Many of the relays were deemed to be at the end of their service life.

Complicating the situation somewhat, no coordination study could be found to verify the settings found. Thus, the relays could only be tested as found, tempered by the experience of the field engineer calibrating the relay as to the intended setting, by comparison to other relays, etc.

4.2.6 Engine Generators

An emergency engine-generator set is provided at both the East and West Ventilation Buildings. Each unit is rated 500kW/625kVA, 480Y/277V, three phase. The generators are located on the ground floor, each in its own room. The generators supply standby power to various tunnel systems and other life safety systems during a failure of the utility power supply system.

The generators were visually inspected. The visual inspections showed both generators to be in good condition with only some minor oil leaks. After the inspections, the generators were tested with a load bank for two hours each. The generator at the West Ventilation Building developed a cooling system problem about ten minutes into the first test. The problem was repaired and the generator was again tested. The testing was conducted by applying the load bank in steps, with the procedure being that each machine would be run for one half hour at each of 25 percent, 50 percent, 75 percent and 100 percent load. The generator in the East Ventilation Building was successfully tested up to 90 percent of its rating, at which point the frequency dropped to a point at which the under-frequency relay would have caused the generator circuit breaker to trip. The generator in the West Ventilation Building was successfully tested up to 80 percent of its rating. Increasing the load to 90 percent caused the frequency to drop to a point where the under-frequency relay caused the generator circuit breaker to trip the unit off-line. The load was decreased back to 80 percent, the breaker was reset, and the last half hour of the test was run at 80 percent load.

During the tests, engine parameters, including vacuum, oil pressure, coolant temperature, engine rpm and oil temperature, were monitored and recorded. All readings were within normal ranges. At the completion of the tests, several of the automatic safety shutdowns were simulated. Engine shutdown occurred for simulated high coolant temperature and for engine overspeed. The shutdown did not function for low oil pressure.

4.2.7 Step Voltage Regulators

The Step Voltage Regulators were installed at both Portal Buildings in 1988. Their function is to maintain a relatively steady voltage supply to the tunnel electrical system, while experiencing variations of + 10% from nominal on the incoming 24.9kV lines. They were installed on the roofs of the portal buildings (essentially at the grade of surrounding land), mounted on double A-frame pole structures.

The visual inspection revealed rusting on the tops of the west side voltage regulators, at the base of the bushings. Also, the "C" phase SL bushing leaked at its base when tightening torque was applied, but stopped when the torque was removed.

The turns ratio of each tap setting was tested and found to be acceptable. Also, the Insulation Resistance was tested and Polarization Index calculated and all found to be acceptable. Similarly, the Insulation Power Factor was tested and found to be acceptable. In addition, the insulating fluid for all regulators was tested for impurities and dielectric strength, and found to be acceptable.

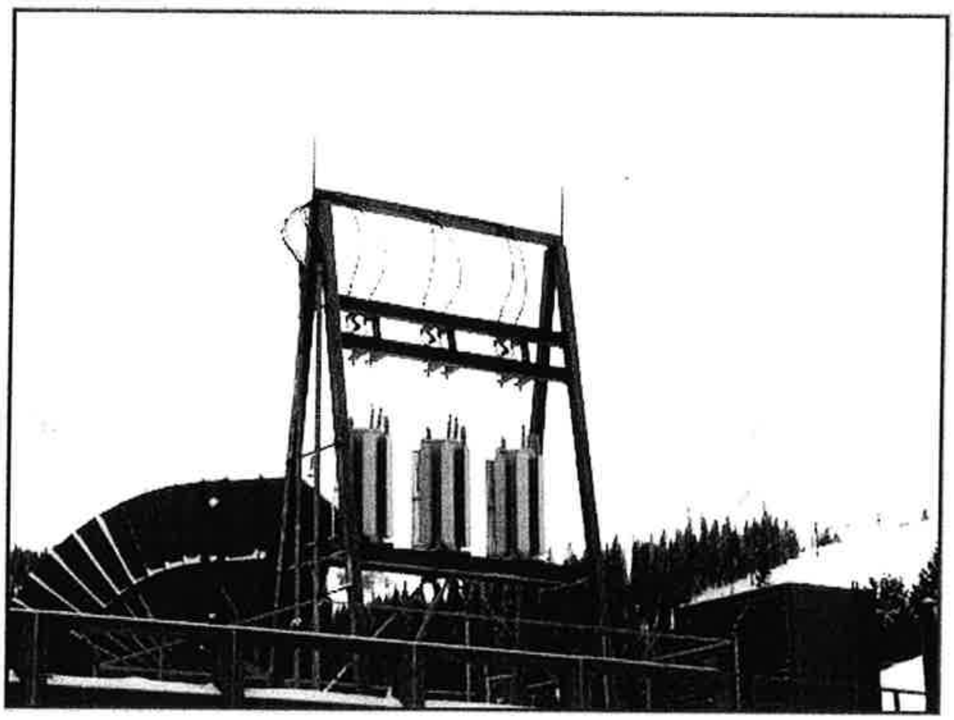


Photo 8—Step Voltage Regulators

4.2.8 Infrared Scan

Various current carrying pieces of equipment were subjected to an infrared inspection, which would detect excess heat being generated due to poor electrical or mechanical connections. No problems were found.

4.2.9 Items Not Tested

The original scope for the testing program included high-potential testing of the incoming 24.9kV cables at both the East and West Portal Buildings, and the tie cable that runs between the two portal buildings in the North Tunnel. This was later changed to Partial Discharge Testing, which is less intrusive to the cables. However, this method requires accessing the cable at a minimum of every 1200 feet. For the tie cable, this would present another set of problems. The pull boxes for this cable are located in the walkway area of the tunnel, and have not been accessed since their installation. To attempt access would require lane shutdowns, and most likely, heroic measures to open them. It was therefore decided to eliminate the testing of these cables.

5.0 RECOMMENDATIONS

Based upon the preceding sections, electrically, the 35 year-old tunnel is holding its own in some areas, while beginning to show its age in others.

5.1 24.9kV Cable

Although the 24.9kV services and tie cable are all functioning normally, it is just a matter of when, not if, they begin to fail. The underground service to the East Portal Building is currently being replaced with an overhead line to the roof mounted step voltage regulator. However, from the regulators to the incoming 24.9kV cubicle, existing conduit and cable (installed at time of regulator installation in 1988) is being utilized. Although not yet at a critical stage, a new 24.9kV service at the West Portal Building, as well as a new 24.9kV tie cable is certainly indicated, and recommended.

Until such time as the tie cable is replaced, it is recommended that the tie cable be kept energized at the full 24.9kV, by closing the circuit breaker at either end, and opening and tagging out the circuit breaker on the opposite end. By virtue of keeping the tie cable energized, its status is always known. In the event a fault develops, it is better to be able to replace/repair the cable at a scheduled time, rather than find out about the fault when it is switched into service because one of the primary services is out. This procedure should also be followed when the new tie cable is ultimately installed.

5.2 24.9kV Switchgear

The main incoming 24.9kV cubicle at the East Portal Building is being rehabilitated as part of the project replacing the underground cable with an overhead line, mentioned above. The existing switchgear is rated for a short circuit interrupting current of 16,735 A @34.5kV, or 23,187A @ 24.9kV, which is well above the available duty from Xcel Energy. Since the duty rating is fine, and there are no apparent problems with this equipment, our recommendation is to leave it as it is (assuming the main incoming cubicle at the East Portal Building is rehabilitated, as mentioned previously).

5.3 Step-Voltage Regulators

The results of electrical and insulating fluid tests for all regulators showed them to be in good electrical condition. The only flaw was that some of the tanks are rusting on the tops, especially at the base of the bushings. The tanks should be cleaned and re-painted.

5.4 Transformers

All power transformers tested fine, both electrically and for condition of insulating fluid. No action is required at this time.

5.5 460V Switchgear

As mentioned in the Inspection and Test Results section, this equipment had a multitude of issues, including difficulty with racking the breakers in and out, lack of lubrication, and leaking gear cases.

The breakers themselves could be sent out to a shop for extensive cleaning and rebuilding, but this probably would not help with the racking in and out of the breakers, without performing extensive work on the breaker cells themselves. Of even greater import, however, are the issues surrounding the protective relays and the duty rating of the switchgear itself. The protective relay situation could be rectified by replacing the series over-current trip units with electronic trip units. However, the big unknown is the actual short circuit duty that the switchgear can endure. No nameplate or other documentation could be located. All things considered, this gear has served for approximately 30 years, and is essentially at the end of its service life. It is recommended that the complete 460V switchgear be replaced.

5.6 2.4kV Switchgear

The 2.4kV switchgear passed all applicable tests. No action required at this time, or in the foreseeable future, for this equipment, other than regular maintenance testing.

5.7 Protective Relays

As indicated by the test reports, the relays are essentially at the end of their service life. Those which are associated with the 460V breakers will automatically be "replaced" by virtue of new electronic trip units being furnished with the new breakers. Various schemes employing the remaining relays, such as undervoltage, current balance, reverse power, etc. should be investigated vigorously, relative to their need or efficacy. Those found unnecessary should be eliminated, and those found to be beneficial should be replaced with new electronic units. The study necessary to determine the ultimate disposition of the subject type of relays is beyond the scope of this report.

5.8 Fan Motors

As mentioned in the Inspection and Test Results Section, out of the equivalent total of 48 single speed 460V motors, and 48 single speed, 2.4kV motors, 13 motors at 460V and 10 motors at 2.4kV exhibited insulation resistance values that were outside the "normal", as evidenced by either their low Dielectric Absorption Ratio or low Polarization Index.

In particular, the 460V motors are EE-2 (12.5HP), ES-1 (600HP), ES-3 (12.5HP and 100HP), ES-4 (600HP), WE-1 (100HP), WE-3 (100HP), WE-4 (12.5HP and 100HP), WS-2 (12.5HP), WS-3 (12.5HP), WS-4 (600HP) and WS-4 (12.5HP). At 2.4 kV, the affected motors are WE-5 (25HP and 200HP), WE-6 (25HP and 200HP), WE-7 (25HP and 200HP), WS-5 (200HP), WS-6 (200HP), and WS-7 (25HP and 200HP).

As a point of information, the Dielectric Absorption Ratio is, in general, the ratio of two time-resistance readings. However, the term is most commonly associated with the resistance readings taken at 60 seconds and 30 seconds. In addition, the ratio obtained by dividing the 10 minute reading by the one minute reading is called the Polarization Index. Without getting into a technical dissertation, suffice it to say that as time during the test passes, the insulation resistance should rise, and the ratios discussed above offer insight into the rate of rise, which in turn, imparts some knowledge about the condition of the insulation, such as degree of brittleness, presence of moisture, etc. None of the motors listed as questionable had ratios which would classify them as "dangerous", i.e., failure imminent.

In addition to analyzing the ratios of insulation resistance, one must also look at the minimum values of insulation resistance measured. In all cases, the minimum value recorded was well in excess of the threshold level which would indicate a problem (1.46 megohm for 460V motors, and 3.4 megohm for 2.4kV motors).

The tests described above provide insight only into the condition of the insulation values to ground. To assess the possible insulation defects from turn-to-turn, coil-to-coil, and phase-to-phase, a surge comparison test must be applied. This was done, and all motors, including those listed at the beginning of this section, passed.

Normally, the decrease in insulation resistance is gradual (over years), giving enough warning, if checked periodically, to permit planned reconditioning before an actual service failure.

The bottom line is that the motors listed should be tested within 4-6 months to determine their possible rate of deterioration of the insulation. In addition, the bearings and alignment of EE-5 should be checked to determine cause of vibration. Also, all motors should be programmed into a schedule which would allow each of them to run, one at a time, for approximately four hours at a time, every 2-3 months. Running the motors for four hours allows the windings to come up to operating temperature, which will help to drive out moisture in the windings. Also, should a motor be ready to fail, the failure will likely happen during one of these runs, and not when a motor is needed for an emergency situation. This would have to be integrated into the operating schedule such that it does not introduce a new electrical demand.

5.9 Engine Generators

The generator supplier should be contacted to determine if either the engine governor can be adjusted to maintain the frequency at higher loadings to prevent the unit from tripping the under-frequency relay, or if the under-frequency relay can be adjusted so that it does not trip when the generator is running at full load.

The emergency power systems should be reviewed to determine the present loads connected to them, to determine whether the present loads are sufficient for safe operation of the tunnel, whether there are additional loads which should be connected to the system, and whether the existing generators have the capacity to serve the required loads. The study necessary to accomplish the above is beyond the scope of this report.

The emergency engine-generator sets should be run with some portion of the emergency load connected at least once a month to keep them exercised and to ensure that they will operate in the event of a power failure. The tests should simulate the loss of normal utility power to approximate an actual power failure and test the automatic starting systems.

5.10 Infrared Scan

The results of the IR Scan, other than flagging excessive dust and dirt accumulation on MCC Nos. 1, 2 and 3 (West Portal Building), did not uncover any abnormal heat build-up.

5.11 Priorities and Costs of Recommendations

The following summarizes the recommendations discussed in this section, adds three additional recommendations, specifies priorities for the recommendations, and assigns estimated costs to the more salient recommendations.

The first additional recommendation is to have a comprehensive short circuit and coordination study for the entire electrical system performed. The need for this manifested itself during the testing phase of this report, when one could not be located. Due to its absence, the relays could only be tested as found, tempered by the experience of the Field Engineer calibrating the relay.

The second "additional" recommendation is to have a comprehensive study of the emergency power system performed. This would include the loads presently connected to the emergency generators, whether they are the proper loads to provide safe operation of the tunnel, whether there are additional loads that should be added to the generators, and whether the existing generators have the capacity to serve the required loads.

The third "additional" recommendation is to have maintenance testing performed on a regular basis. This can be accomplished by a combination of CDOT tunnel personnel and an outside testing company. For instance, the insulation resistance of the fan motors can be determined by CDOT personnel as the fans are available, while relay testing would be performed by a testing company. Our recommendation would be to follow the InterNational Electrical Testing Association, Inc.'s "MTS-2001 Appendix B", Frequency of Maintenance Tests, utilizing a matrix multiplier of 1.0.

Other general recommendations include keeping the 24.9kV tie cable energized at all times, and operating each of the fan motors for approximately four hours on a quasi-regular basis.

Recommendations due to results of the testing program include the following:

Replace 460V switchgear and all protective relaying at both portal buildings, for an approximate cost of $3,100,000. The cost is much higher than what normally might be expected. This is due to the fact that since this is an existing facility, it is not possible to simply take the switchgear out of service and replace it. Rather, a temporary work-around must be installed to allow the tunnel to remain functional, and then be removed, once the new switchgear has been installed. This has to occur at both Portal buildings in turn. The estimate does reflect the fact that the temporary equipment can be utilized at both buildings, in turn.

Check bearings and alignment of fan motor EE-5 to determine cause of vibration.

Re-test indicated fan motors in approximately 4-6 months to determine the possible rates of deterioration of their insulation.

Check with emergency generator supplier/manufacturer to determine if adjustments can be made to prevent tripping as loads approach full capacity.

Paint tops of step-voltage regulators.

One other recommendation, which is mentioned in the report, but is not as a result of testing, is the replacement of the existing 24.9kV electrical service at the West portal building, as well as replacement of the existing 24.9kV tie cable, which presently is routed through the North Tunnel. An approximate cost is $490,000, which takes into account that for the tie cable, work will be performed at off-hours, with a lane shut-down. Also, the manholes involved have probably not been opened for many years, and since they have bolted covers, the time required to open, clean, and rehabilitate them could be quite time consuming.

It should be noted that the first two recommendations (short circuit/coordination and emergency power studies) are engineering tasks, and accordingly, since the cost of these types of services are normally arrived at by a proposal process, no amounts are given here. Likewise, the order of magnitude costs for replacement of the 460V switchgear/relays, as well as that for replacement of 24.9kV service and tie cables do not include engineering costs.

From a reliability and operational viewpoint, the first priority would be replacement of the 460V switchgear and all protective relaying, followed closely by the replacement of the aforementioned 24.9kV cables. The studies relative to short circuit/coordination and emergency power, should be initiated as soon as possible, and could be accomplished concurrent with the engineering for the 460V switchgear replacement. The remainder of the recommendations do not have a significant dollar impact and thus no estimates for them are being furnished.

Appendix 1

Cost Estimates

480 volt Switchgear Replacement
Estimate Summary

East Ventilation Building	$1,700,000
West Ventilation Building	$1,400,000
Total	**$3,100,000**

480 volt Switchgear Replacement
East Ventilation Building

	Quan	Unit	Unit Cost	Extension
<u>Temporary</u>				
3000A Feeder Bus Duct	150	LF	450	$67,500
3000A Plug In Bus Duct	60	LF	450	$27,000
Transformer Connection	2	EA	3500	$7,000
Switch Connection	4	EA	3500	$14,000
Edgewise Elbows	6	EA	3600	$21,600
Flatwise Elbows	6	EA	3600	$21,600
Tees	2	EA	4800	$9,600
Ends	2	EA	300	$600
1200A Fused Switch bolt-ons	9	EA	10100	$90,900
Flatwise Hangers	35	EA	70	$2,450
Hanger Rod Sets	44	EA	1050	$46,200
3000A Bolted Pressure Switch	2	EA	13600	$27,200
1200A MLO Fused Switchboard w/ 5-400A, 1-800A	1	EA	9000	$9,000
Relocate Feeders from Existing Swgr to Temp Swbd	5	EA	5000	$25,000
Cable Connections from Bus Duct Switches to Starters and Swbd	9	EA	3600	$32,400
Disconnect Existing Bus Duct Connections from Transformers	2	EA	2100	$4,200
Labor Adder for level of difficulty, premium time, etc.	1	EA	16000	$16,000
<u>Demolition</u>				
Remove Existing Switchgear	1	LS	10500	$10,500
Remove Existing Bus Duct	140	LF	125	$17,500

<u>Permanent</u>				
Switchgear c/o	1	EA	225000	$225,000
3000A Main, Bus Duct Connected	2	EA	1300	$2,600
3000A Tie	1	EA	400	$400
1200A Branch	8	EA	650	$5,200
400A Branch	4	EA	200	$800
800A Branch	1	EA	300	$300
Sections	7	EA	600	$4,200
Shipping Splits	3	EA	200	$600
Size 7 Magnetic Starter, NEMA 1 Enclosure	8	EA	19600	$156,800
3000A Feeder Bus Duct	140	LF	715	$100,100
Transformer Connection	2	EA	3500	$7,000
Flatwise Elbows	2	EA	3600	$7,200
Edgewise Elbows	4	EA	3600	$14,400
Flatwise Hangers	20	EA	70	$1,400
Hanger Rod Sets	20	EA	1050	$21,000
Extend 600HP Motor Feeders to New Starters	8	EA	8000	$64,000
Labor Adder for level of difficulty, premium time, etc.	1	EA	16000	$16,000
<u>Demolition of Temporary</u>				
Remove Temporary Bus Duct and Fittings	210	LF	125	$26,250
Remove Temporary Switchboard	1	EA	2500	$2,500
Remove Temporary Conduit and Wire	1	LS	3500	$3,500
Subtotal				$1,109,500
Contingency 15%				$166,425
Subtotal				$1,275,925

Subcontractor Overhead and Profit 20%	$255,185
Subcontractor Total	$1,531,110
General Contractor Overhead and Profit 10%	$153,111
Total	$1,684,221
	$1,700,000

480 volt Switchgear Replacement
West Ventilation Building

	Quan	Unit	Unit Cost	Extension
Temporary				
3000A Feeder Bus Duct	150	LF	175	$26,250
3000A Plug In Bus Duct	60	LF	175	$10,500
Transformer Connection	2	EA	600	$1,200
Switch Connection	4	EA	600	$2,400
Edgewise Elbows	6	EA	700	$4,200
Flatwise Elbows	6	EA	700	$4,200
Tees	2	EA	1750	$3,500
Ends	2	EA	125	$250
1200A Fused Switch bolt-ons	9	EA	1850	$16,650
Flatwise Hangers	35	EA	70	$2,450
Hanger Rod Sets	44	EA	1050	$46,200
3000A Bolted Pressure Switch	2	EA	2100	$4,200
1200A MLO Fused Switchboard w/ 5-400A, 1-800A	1	EA	2500	$2,500
Relocate Feeders from Existing Swgr to Temp Swbd	5	EA	5000	$25,000
Cable Connections from Bus Duct Switches to Starters and Swbd	9	EA	3600	$32,400
Disconnect Existing Bus Duct Connections from Transformers	2	EA	2100	$4,200
Labor Adder for level of difficulty, premium time, etc.	1	EA	16000	$16,000
Demolition				
Remove Existing Switchgear	1	LS	10500	$10,500
Remove Existing Bus Duct	140	LF	125	$17,500

Permanent				
Switchgear c/o	1	EA	225000	$225,000
3000A Main, Bus Duct Connected	2	EA	1300	$2,600
3000A Tie	1	EA	400	$400
1200A Branch	8	EA	650	$5,200
400A Branch	4	EA	200	$800
800A Branch	1	EA	300	$300
Sections	7	EA	600	$4,200
Shipping Splits	3	EA	200	$600
Size 7 Magnetic Starter, NEMA 1 Enclosure	8	EA	19600	$156,800
3000A Feeder Bus Duct	140	LF	715	$100,100
Transformer Connection	2	EA	3500	$7,000
Flatwise Elbows	2	EA	3600	$7,200
Edgewise Elbows	4	EA	3600	$14,400
Flatwise Hangers	20	EA	70	$1,400
Hanger Rod Sets	20	EA	1050	$21,000
Extend 600HP Motor Feeders to New Starters	8	EA	8000	$64,000
Labor Adder for level of difficulty, premium time, etc.	1	EA	16000	$16,000
Demolition of Temporary				
Remove Temporary Bus Duct and Fittings	210	LF	125	$26,250
Remove Temporary Switchboard	1	EA	2500	$2,500
Remove Temporary Conduit and Wire	1	LS	3500	$3,500
Subtotal				$889,350
Contingency 15%				$133,403
Subtotal				$1,022,753

Subcontractor Overhead and Profit 20%	$204,551
Subcontractor Total	$1,227,303
General Contractor Overhead and Profit 10%	$122,730
Total	$1,350,033
	$1,400,000

480 volt Switchgear Replacement Procedure

The proposed procedure for the replacement of the 480 volt switchgear at the Tunnel includes the installation of temporary equipment to enable the tunnel electrical systems to remain functional during the installation of the new electrical equipment. The installation will proceed in one ventilation building, and when the first building is complete, the work will commence in the second building. This will allow the same temporary equipment to be used in both buildings.

The temporary installation will consist of two new fusible bolted pressure switches, bus duct connected one to each existing 2000kVA transformer, and serving as main disconnecting means and overcurrent devices. The load side of the two switches will be tied together with bus duct, and the bus duct continued to the proposed location of the temporary switchboard and the new motor starters for the 600HP motors. The main switches will be key-interlocked such that only one of the switches may be in the closed position at any time. New NEMA size 7 magnetic starters in freestanding enclosures will be installed for the 600HP fan motors, and a switchboard will be installed for the other loads served from the existing switchgear. Fusible plug-in switches will be installed on the bus duct to supply each of the motor starters and the temporary switchboard.

The temporary equipment will be installed prior to the existing system being taken out of service. Once the system is in place, the transformers will be connected to supply both the temporary system and existing systems. Then the loads will be cut over one at a time from the existing switchgear to the temporary system. When the loads are completely connected to the temporary system, the existing switchgear will be taken out of service and removed. The new switchgear will then be installed.

Once the new switchgear is in place, it will be connected to the existing transformers again such that both the temporary and the new switchgear are energized. The loads will then be reconnected back to the new switchgear. The motor starters installed as part of the temporary installation will remain as a permanent part of the power system.

After the completion of the first ventilation building, the temporary equipment will be moved to the remaining ventilation building and the procedure repeated in that building.

24.9kV Tie Cable Replacement Estimate

	Quan	Unit	Unit Cost	Extension
Rehabilitate Tunnel Manholes/Covers	23	EA	1425	$32,775
Rod, Mandrel, Brush, and Swab Conduit	24	Sections	1800	$43,200
Install Tunnel Cable	22	Sections	5700	$125,400
Install Swgr. To Tunnel Cable	2	Sections	6600	$13,200
Splice Tunnel Cable	23	Sets	1665	$38,295
Terminations at Swgr.	2	Sets	1730	$3,460
Testing, Phasing, Etc.	1	EA	1200	$1,200
Remove Existing Tie Cable	24	Sections	900	$21,600

Subtotal	$279,130
Contingency 15%	$41,870
Subtotal	$321,000
Subcontractor Overhead and Profit 20%	$64,200
Subcontractor Total	$385,199
General Contractor Overhead and Profit 10%	$38,520
Total	$423,719

$425,000

24.9kV Service at West Portal Estimate

	Quan	Unit	Unit Cost	Extension
Remove Existing Cable and Install Pull Line - Pole to MH	1	Sections	1200	$1,200
Rod, Mandrel,Brush, and Swab Above Conduit - Pole to MH	1	Sections	1200	$1,200
Install New Cable in Above Conduit - Pole to MH	1	Sections	5400	$5,400
Remove Existing Cable and Install Pull Line - MH to Swgr.	1	Sections	1200	$1,200
Rod, Mandrel,Brush, and Swab Above Conduit - MH to Swgr.	1	Sections	1200	$1,200
Install New Cable in Above Conduit - MH to Swgr.	1	Sections	4200	$4,200
Remove and Replace Cable - Swgr. To Volt. Reg.'s	1	Sections	4800	$4,800
Remove and Replace Cable - Volt. Reg.'s to Swgr.	1	Sections	4800	$4,800
Install Splices	2	Sets	400	$800
Install Terminators	4	Sets	800	$3,200
Testing, Phasing, Etc.	1	EA	800	$800
Labor Adder for Degree of Difficulty, Access Restraints, Switching and Tagging, Etc.	1	EA	12600	$12,600

Subtotal	$41,400
Contingency 15%	$6,210
Subtotal	$47,610
Subcontractor Overhead and Profit 20%	$9,522
Subcontractor Total	$57,132
General Contractor Overhead and Profit 10%	$5,713
Total	$62,845

$65,000

CDOT – E/J Tunnel
Replace 24.9KV Tie Cable
Cost Estimate

Assumptions:

1. All work will be done at off-hours, with a lane shut-down.

2. Consider time for tagging, etc. (work in swgr.– both ends)

3. Tunnel is approx. 9,000 ft. long, with 23 manholes.
   Average tunnel section length = 9,000 / 22 = 400'
   Switchgear to MH # 1M 1 section w/1-90°, 1-60° bend
   MH # 1M to MH # 23M 22 sections – straight pulls
   MH # 23M to Switchgear 1 section w/1-90°, 1-60° bend
   All conduit is 4" transite

4. Tunnel manhole covers have not been removed for years, if ever. The assumed time to remove bolts, lift cover, clean manhole, and repair as necessary to enable re-closing of cover, will take a 3-man crew approx. 4 hours/manhole, on OT, with a lane shutdown. In addition, assume that half of the covers (say 12) have to be replaced.

5. After manholes have been cleaned, repaired, etc., the time to open covers, install lead line, then pull rope, and to mandrel, wire brush, swab, leave pull line installed, and replace covers, for a 400' section, will be approx. 4 hours for two 3-man crews, i.e., 24 manhours / section.

6. Actual cable pulling, time is assumed at 2 hours / tunnel section with two 3-man crews, i.e., 12 man hours / section.

7. For "end" sections, i.e., from / to swgr., to / from "1st" or "last" MH, use 4 hours, to compensate for switching, tagging time, etc. at swgr. ends, i.e., (4)(2)(3)=24 manhours.

8. For splicing, use 4 hours per MH with a 2-man crew, i.e., 8 man hours / manhole.

9. For terminations at swgr. ends, use 8 hours with a 2-man crew- extra time allotted for switching, tagging, mounting, etc., i.e., 16 manhours.

10. For testing, phasing, etc., use 4 hours with two 2-man crews, i.e. 16 manhours

11. Existing tie cable will be removed, with pull line being left in its place. Use two 3-man crews for 2 hours per section, including cutting up old cable, i.e., 12 hours / section