Pipe-RU6558

Study of the Effects of Buried Pipe Integrity on Roadway Subsidence

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16. Abstract

The performance of roadway pavement is significantly affected by the integrity of buried pipes underneath. It is important that these pipes remain structurally sound during the life of the roadway for a better performance and uninterrupted service. Damage or total loss of the pipe will result in structural damage to the pavement, excessive deflections, and roadway subsidence or collapse. In the event of a roadway subsidence or collapse, the roadway or sections of it will be fully or partially closed to traffic for repair. Road closure and detours would cost the traveling public (trucking industry and passenger vehicles) in travel delay and added vehicle operating costs. One-lane closures usually result in approximately 30-60 minutes of delay per vehicle, and would cost the public in gas costs and additional costs due to travel delays. The added cost of travel would cause loss of revenues for businesses in New Jersey.

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EFFECT OF BURIED PIPE INTEGRITY ON ROADWAY SUBSIDENCE

INTRODUCTION

In the past several years, there have been several fire incidents that have dramatically compromised the structural integrity of two heavily traveled New Jersey roadways: I-80 and Route 9. On June 22, 2001, after a collision, a fuel truck burst into flames on I-80 near Denville sending 3,200 gallons of flammable gasoline into the storm drains. On October 20, 2004, a fuel tanker flipped over and burst into flames on Route 9 near Sayreville sending 9,000 gallons of flammable gasoline into the storm drains where it continued to burn. Luckily, in both cases, the storm drains did not lose integrity and remained structurally sound after the fire. However, storm drains with low fire resistance could lose structural integrity causing the roadway to subside or collapse. As a result of these and other incidents, the effect of buried pipe integrity on roadway subsidence was evaluated for a no-access interstate freeway and for a full access arterial roadway, both falling under the auspices of the NJDOT. Figures 1 and 2 show traffic on I-80 near Exit 38 and on Route 9 near Newark respectively.

SUMMARY

The performance of roadway pavement is significantly affected by the integrity of buried pipes underneath. It is important that these pipes remain structurally sound during the life of the roadway for a better performance and uninterrupted service. Damage or total of loss of the pipe will result in structural damage to the pavement, excessive deflections, and roadway subsidence or collapse. In the event of a roadway subsidence or collapse, the roadway or sections of it will be fully or partially closed to traffic for repair. Road closure and detours would cost the traveling public (trucking industry and passenger vehicles) in travel delay and added vehicle operating costs. One-lane closures usually result in approximately 30-60 minutes of delay per vehicle, and would cost the public in

gas costs and additional costs due to travel delays. The added cost of travel would cause loss of revenues for businesses in New Jersey.

This report summarizes the results of an analytical investigation of the effect of buried pipe integrity on roadway subsidence. Three different pipe diameters were evaluated using typical cover on top of pipe and typical trench widths. The pipe diameters were: 24 in., 36 in., and 48 in. The pavement cross-section selected for this investigation was typical for I-80 and Route 9 in New Jersey. The applied loading consisted of an HS-25 truck wheel load. Two loading cases were analyzed: 1) buried pipes perpendicular to the roadway, and 2) buried pipe parallel to the roadway. The results showed that for the case when the pipe is perpendicular to traffic and when the pipe is completely damaged, the pavement on top of the pipe suffers excessive deformations and eventually collapses. In many of the cases investigated in this study, the roadway collapse occurred under the pavement and soil self weight without vehicular loads. In other cases, the collapse occurred due to moving vehicular loads. The collapse mechanisms were dependent on the pavement and soil strength and pipe diameter. When the damaged pipe is parallel to traffic, the pavement suffers considerable deformations in the case of the 24 in. pipe and it collapsed in the case of 36 in. and the 48 in. pipes.

EFFECT OF PIPE LOSS ON ROADWAY PERFORMANCE

The effect of pipe damage or pipe loss below roadway surface was evaluated using analytical simulations. The simulations were modeled using finite element analysis. The finite element analysis method is well suited for the analysis of soil structure interaction. A two-dimensional model was created for the soil-pipe-pavement system using roadway cross-sections typical for I-80 and Route 9 in New Jersey. The roadway sections of I-80 and Route 9 are variable along the length of these roads because of the several repairs, overlays, and widening over the years; hence, the chosen cross section was a typical section representative of these roadways. The profile of the soil and pavement surrounding the buried pipe has several layers of compacted soils on top of the pipe, base and sub base layers, and asphalt concrete layers. Typical roadway sections for I-80 and

Route 9 are shown in Figures 3, 4, and 5 for the 24-in diameter pipe, the 36-in diameter pipe, and the 48-in diameter pipe respectively.

The standard truck loads in New Jersey are the AASHTO HS-20 Truck and Lane loads and the Permit loads. The NJDOT specs also require increasing this load by 25% for moment and shear calculations. The controlling load in our study was the truck load. The truck loads consist of several concentrated wheel loads depending on the number of axles. The maximum wheel load of the HS-20 Truck is 16 kips. This wheel load is increased by 25% for design. Hence, a 20 kip concentrated wheel load was the vehicular load used in this study. The concentrated load was applied as a moving load such that it produces the maximum stresses and deformations in the system.

Case 1: 24-in Diameter Buried Pipe Perpendicular To Traffic

For this case, a computer model was created to simulate a 24-in diameter hole under the roadway as was shown in Figure 3. The roadway section on top of the pipe consisted of about 2 ft of compacted backfill, 2 ft of sub base and base materials, and about 16 in of base course and asphalt concrete pavement. The width of the trench was 48 in. Figure 6 shows the roadway response as the vehicular load approaches the damaged pipe location from left to right. The results show that roadway deformations are induced when the vehicle is about 4 ft to 6 ft from the buried hole. As the vehicle moves closer to the hole, the deformations increase. The maximum deformations occurred when the load was over the buried hole. These vertical deformations became excessive as the load approached the buried pipe location, and resulted in roadway subsidence and collapse as the vehicle load passes over the hole. Figures 7, 8, and 9 show soil plasticization, soil vertical displacements, and soil vertical stresses due to loss of pipe support respectively. The soil plasticization shown in Figure 7 indicated that the soil has reached a plastic state (irreversible deformations) in these shaded regions making it incapable of supporting applied loads thus leading to failure. Figure 8 shows that the maximum vertical deformations occur at the pipe location. Figure 9 shows that the stresses in the soil over the lost pipe are very small while the stresses on either side of the trench are maximum.

This indicates that, the soil on either side of the trench is picking up the load that was supported by the pipe and the roadway above it and that the soil on top of buried pipe can not support any loads any more. For weaker soils, the analysis showed that the roadway collapses under the pavement and the soil's own self-weight without the application of any moving vehicular loads.

Case 2: 36-in Diameter Buried Pipe Perpendicular To Traffic

For this case, a computer model was created to simulate a 36-in. diameter hole under the roadway as was shown in Figure 4. The roadway section on top of the pipe was similar to the case of the 24-in. pipe except that the trench width was increased to 78 in. For the case of this pipe diameter, the analysis showed that roadway deformations are induced at the instant the pipe is lost and without the application of any moving loads. These deformations quickly become excessive and the roadway subsided and eventually collapses. Figure 10 shows the soil plasticization (soil failure) under the weight of roadway pavement and the compacted fill material over the damaged pipe. This is a serious situation because a sudden large depression has developed in the roadway without a warning. Several additional runs for this case were made using a stronger soil. These runs showed that although the stronger soil did not collapse under its own weight, it did collapse under the moving vehicular loads. Figures 11 and 12 show the vertical displacements and stresses for the case of the 36-in. diameter buried pipe respectively.

Case 3: 48-in Diameter Buried Pipe Perpendicular To Traffic

For this case, a computer model was created to simulate a 48-in. diameter hole under the roadway. The roadway section on top of the pipe was similar to the case of the 24-in. pipe except that the trench width was increased to 90 in. Figure 13 shows the soil plasticization (soil failure) under the weight of roadway pavement and the compacted fill material over the damaged pipe. This is a serious situation because a sudden large depression has developed in the roadway without a warning. Several additional runs for this case were made using a stronger soil. These runs showed that although the stronger soil did not collapse under its own weight, it did collapse under the moving vehicular loads. Figures 14 and 15 show the vertical displacements and stresses for the case of the 48-in. diameter buried pipe respectively.

Case 4: Buried Pipes Parallel to Traffic

Buried pipes parallel to traffic are typically located about 4 ft. to 6 ft. from the moving wheel loads. Therefore this case can be analyzed using the cases of pipes perpendicular to traffic with the moving load located about 4 ft. to 6 ft. from the buried pipe. For the 24-in. pipe, the analysis in Case 1 showed that when the moving load is about 4 ft. to 6 ft. from the pipe, deformations are induced in the road way. However, for the 36-in and the 48-in., the self-weight causes excessive deformations in the roadway and eventual collapse without any moving loads.

EFFECT OF PAVEMENT DAMAGE ON ROADWAY SERVICE

I-80

Roadway subsidence and pavement damage in the vicinity of a damaged buried pipe will result in major disruption of traffic in the region for an extended period of time and will require millions of dollars to keep this segment of the highway open. I-80 provides direct access for commercial trucking year round, as well as passenger cars and recreational traffic. It is also a major source of support and survival for businesses along the path of the Interstate in New Jersey. Pavement damage due to loss of pipe integrity may result in full or partial closure depending on the extent of damage. In either case, traffic will be disrupted and alternative routes will cost additional time and money.

The NJDOT traffic volume data for I-80 for weekdays in year 2004 show that the Average Daily Traffic (ADT) for the eastbound of I-80 in New Jersey was 47,692 passenger cars, 29,044 two-axle trucks (4-Tire and 6-Tire), and 3,496 five-axle trailers.

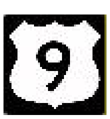
For the westbound, the ADT was 59,937 passenger car, 25,135 two-axle trucks (4-Tire and 6-Tire), and 4,239 five-axle trailers. The 2004 Average Annual Daily Traffic (AADT) for I-80 for weekdays was 83,916 vehicles for the eastbound and 92,714 vehicles for the westbound.

For the weekends in year 2004, the NJDOT traffic data show that the ADT for the eastbound of I-80 is as follows: 39,402 passenger cars, 21,230 two-axle trucks (4-Tire and 6-Tire), and 1,104 five-axle trailers. For the westbound, the ADT's were 51,004 passenger car, 18,272 two-axle trucks (4-Tire and 6-Tire), and 1,219 five-axle trailers. The AADT for eastbound was 62,948 vehicles and for the westbound was 74,074 vehicles.

A total closure of the highway in two directions will affect approximately a total of 176,630 vehicles daily for weekdays. A partial closure or individual lane closure will affect a portion of that volume depending on the magnitude, the location, and the time of the day of the partial closure. Table 1 summarizes the daily traffic data for I-80 on weekdays and Table 2 summarizes the daily traffic data for I-80 on weekends.

The highway closure will incur additional daily costs to the trucks carrying goods along the Interstate in thousands of dollars per day. This would translate to added shipping costs for goods transported to and from the region. The added shipping costs would in turn affect the economic competitiveness for the goods produced in New Jersey and the Northeastern region in general.

US Route 9



The roadway subsidence and the subsequent pavement damage in the vicinity of a damaged buried pipe will result in major disruption of traffic in the region for an extended period of time and will require millions of dollars to keep this segment of the highway open. US Route 9 provides direct access for commercial trucking year round, as well as passenger cars and recreational traffic. It is also a major source of support and survival for businesses along the path of Route 9 in New Jersey. Pavement damage due to loss of pipe integrity may result in full or partial closure depending on the extent of damage. In either case, traffic will be disrupted and alternative routes will cost additional time and money.

The NJDOT traffic volume data for Route 9 for weekdays in year 2004 shows that the Average Daily Traffic (ADT) for the northbound of US Route 9 in New Jersey was 14,702 passenger cars, 11,289 two-axle trucks (4-Tire and 6-Tire), and 208 five-axle trailers. The 2004 Average Annual Daily Traffic (AADT) for weekdays for Route 9 northbound was 26,813 vehicles.

For the weekends in year 2004, the NJDOT traffic data show that the ADT for the northbound of Route 9 was as follows: 13,924 passenger cars, 9,481 two-axle trucks (4-Tire and 6-Tire), and 51 five-axle trailers. The AADT for weekends for the northbound of Route 9 was 23,612 vehicles. Because no traffic counts were available from the NJDOT for the southbound of Route 9, it was assumed that the traffic counts for the northbound and the southbound were similar.

Therefore, a full closure of Route 9 in two directions will affect approximately a total of 53,626 vehicles daily for weekdays. A partial closure or individual lane closure will affect a portion of that volume depending on the magnitude, the location, and the time of the day of the partial closure. Table 3 summarizes the daily traffic data for US Route 9 northbound on weekdays and Table 4 summarizes the daily traffic data for US Route 9 northbound on weekends. Table 5 shows a summary of the average daily traffic volumes for 2004 for Route 9 northbound only and I-80.

The highway closure will incur additional daily costs to the trucks carrying goods along US Route 9 in thousands of dollars per day. This would translate to added shipping costs for goods transported to and from the region. The added shipping costs would in turn affect the economic competitiveness for the goods produced in New Jersey and the Northeastern region of the United States.

COST OF TRAFFIC DIVERSION AND ROAD REPAIR

Buried Pipes Perpendicular to Traffic (I-80 and Route 9)

For buried pipes that are perpendicular to traffic, removal and installation of a new buried pipe system is most likely to result in full closure of traffic. Full closure of traffic on a typical section on a typical day of I-80 eastbound or westbound would require diverting approximately 54,000 passenger vehicles, 25,000 two-axle trucks, and about 5,000 five-axle trucks to alternate routes. It is estimated that a typical length of an alternate route (detour) is about 10 miles. The cost of this traffic diversion from increased gas consumption, additional driver and passenger commuting time, damaged goods, and other interruptions, is estimated at $1,200,000 per day. The removal of the damaged pavement and pipe materials and the excavation, installation of new pipe, and repaving would require several days. It is estimated that the cost of removal of damaged pavement and pipe materials, cleaning of the drains, and the installation of a new drainage pipe system for a typical 100 ft length of the pipe is about $50,000 for the 24-in diameter pipe, $60,000 for the 36-in diameter pipe, and $70,000 for the 48-in pipe. These estimates include labor, equipment, and materials. The installation of a new pipe system includes the cost of removal of damaged pipes and manholes, cleaning of the drains, installation of a new pipe, new drains and manholes and repaving. The time needed to complete 100 ft of pipe removal and installation with an accelerated schedule and with incentives is estimated at five days assuming good weather conditions. Therefore the total estimated cost for five days of traffic closure of I-80 will be approximately $6 million in addition to the installation costs.

For Route 9, the full closure of traffic on a typical section on a typical day of Route 9 northbound would require diverting approximately 15,000 passenger vehicles, 10,000 two-axle trucks and about 200 five-axle trucks to alternate routes. It is estimated that the typical length of an alternate route (detour) is about 5 miles. Applying the same methods of cost estimates used for I-80, the full closure of Route 9 northbound will cost about $700,000 per day and the total estimated cost for a five days of traffic closure is about $3.5 million in addition to the installation costs. Similar cost estimates for full closure of Route 9 southbound are to be expected. Cost estimates for full road closure and pipe replacement for I-80 and Route 9 are given in Table 6.

Buried Pipes Parallel to Traffic (I-80 and Route 9)

For buried pipes that are parallel to traffic, the damage of the buried pipe may or may not result in pavement collapse. Whether the pavement over the pipe collapses or suffers severe deformations, it is anticipated in this case that the damaged pavement is unlikely to result in full closure of traffic. Rather, a partial closure of at least one lane will occur. Closing one lane of traffic on I-80, will not require alternate routes but will result in significant traffic delays. The cost of these traffic delays resulting from increased gas consumption, additional driver and passenger commuting time, more vehicle use, damaged goods, and other interruptions, is estimated at about $400,000 per day. Closing one lane of traffic on Route 9 will not require alternate routes but will result in significant travel delays depending on the section of Route 9 where the traffic is interrupted. The cost of this traffic delay resulting from increased gas consumption, additional driver and passenger commuting time, damaged goods, and other interruptions, is estimated at about $250,000 per day. The removal of the damaged pavement and pipe materials and the excavation, installation of new pipe, and repaving would require five days. It is estimated that the cost of removal of damaged pavement and pipe materials, cleaning of the drains, and the installation of new drainage pipe system for a typical 100 ft length of the pipe is about $50,000 for the 24-in diameter pipe, $60,000 for the 36-in diameter pipe, and $70,000 for the 48-in pipe. These estimates include labor, equipment, and materials. The installation of a new pipe system includes the cost of the removal of damaged pipes and manholes, cleaning of the drains, installation of a new pipe, new drains and manholes and repaving. The time needed to complete a 100 ft of pipe removal and installation with an accelerated schedule and with incentives is estimated at five days assuming good weather conditions. Therefore the total estimated cost for five days of one lane closure on I-80 will be approximately $2 million in addition to the installation costs. On Route 9, the total estimated cost for five days of one lane closure will be approximately $1.21 million dollars in addition to installation costs. Cost estimates for partial road closure and pipe replacement for I-80 and Route 9 are given in Table 6.

CONCLUSIONS

Based on the results of this study, the following conclusions are made:

1. The loss of buried pipes perpendicular to the roadway surface resulted in roadway subsidence and collapse in the vicinity of the pipe. For the typical roadway cross sections analyzed in this study, namely, I-80 and Route 9, the roadway subsided and then collapsed under its own weight without application of any moving loads.

2. Analysis of the same typical sections for buried pipes perpendicular to traffic using stronger soils showed that the roadway did not collapse under its own weight but did collapse under moving vehicular loads. The stronger soil, under its own weight, did not collapse but suffered excessive deformations.

3. The analysis showed that the same failure mechanisms (roadway collapse) were observed for the 24-in, 36-in, and 48-in, pipe diameters evaluated in this study.

4. For the case where the pipes are parallel to traffic, the roadway surface suffered excessive deformations under its own weight. Collapse was observed in several cases under moving vehicular loads depending on the location of the moving load and the roadway profile.

5. The total cost of road repair, a 36-in diameter pipe replacement, and traffic diversion due to road closure for five days was approximately $6.06 million dollars for I-80 and $3.56 million dollars for Route 9.

6. The total cost of road repair, a 36-in diameter pipe replacement, and traffic delays due to one lane closure for five days was approximately $2.06 million dollars for I-80 and $1.21 million dollars for Route 9.

Table 1. I-80 Traffic Volume Data for Weekdays. (NJDOT, 2004)

LOCATION: I-80 , MP 66.2, South Hackensack, Bergen Co.
F.C.= 11

MONTH	DIR	Unclass	Motor-cycle	Auto	2-Axle 4-Tire	Bus	2-Axle 6-Tire	3-Axle 1-Unit	4-Axle 1-Unit	<=4-Axle 1-Trailer	5-Axle 1-Trailer	>=6-Axle 1-Trailer	<=-Axle 2-Trailer	6-Axle 2-Trailer	>=7-Axle 2-Trailer	MONTHLY ADT EB WB	MONTHLY ADT COMBINE
		0	1	2	3	4	5	6	7	8	9	10	11	12	13		
JAN 2004	EB	1,039	-	40,075	26,036	761	3,220	664	74	579	3,243	21	83	21	-	75,816	
	WB																
FEB 2004	EB	1,057	-	43,479	27,824	919	3,119	707	60	621	3,349	23	104	27	1	81,290	
	WB																
MAR 2004	EB	1,096	-	43,757	27,061	892	3,174	745	110	618	3,409	25	111	29	1	81,028	
	WB																
APR 2004	EB	1,161	-	46,010	28,198	954	3,011	806	174	645	3,632	31	118	27	1	84,768	
	WB																
MAY 2004	EB	1,322	-	47,031	28,622	1,016	3,155	851	200	651	3,778	38	114	31	1	86,810	
	WB																
JUN 2004	EB	1,458	-	47,730	28,717	1,025	3,590	846	193	692	3,641	42	111	35	1	88,081	
	WB																
JUL 2004	EB	1,050	-	46,157	28,772	934	2,896	845	231	656	3,462	41	106	28	1	85,179	
	WB	828	-	61,341	17,798	470	3,878	1,127	80	600	4,428	51	108	27	1	90,737	175,916
AUG 2004	EB	496	-	46,071	29,446	1,010	3,017	875	211	688	3,578	39	115	29	1	85,576	
	WB	726	-	61,615	18,662	590	5,543	1,173	102	693	4,612	56	125	32	1	93,930	179,506
SEP 2004	EB	846	-	49,648	23,338	802	4,051	828	206	629	3,337	35	104	28	1	83,853	
	WB	736	-	60,914	18,501	563	5,348	1,074	116	655	4,481	50	124	29	2	92,593	176,446
OCT 2004	EB	767	-	55,861	19,918	698	3,765	905	245	658	3,601	37	117	27	1	86,600	
	WB	849	-	59,896	19,205	563	7,911	1,132	129	745	4,516	48	132	33	1	95,160	181,760
NOV 2004	EB	998	-	53,120	19,264	678	3,784	863	220	602	3,342	36	108	28	1	83,044	
	WB	990	-	59,004	18,942	499	7,034	961	119	821	3,617	36	107	26	1	92,157	175,201
DEC 2004	EB	831	-	53,365	21,128	645	3,422	946	184	678	3,576	37	111	25	2	84,950	
	WB	715	-	56,851	19,232	530	8,760	923	105	624	3,778	44	112	28	2	91,704	176,654
AVERAGI	EB	1,010	0	47,692	25,694	861	3,350	823	176	643	3,496	34	109	28	1	83,916	
	WB	807	0	59,937	18,723	536	6,412	1,065	109	690	4,239	48	118	29	1	92,714	176,630
TOTAL (EB+WB)		1,817	0	107,629	44,417	1,397	9,763	1,888	284	1,333	7,734	81	227	57	2	176,630	
% DAILY	EB	1.2%	0.0%	56.8%	30.6%	1.0%	4.0%	1.0%	0.2%	0.8%	4.2%	0.0%	0.1%	0.0%	0.0%	100.0%	
	WB	0.9%	0.0%	64.6%	20.2%	0.6%	6.9%	1.1%	0.1%	0.7%	4.6%	0.1%	0.1%	0.0%	0.0%	100.0%	
% TOTAL		1.0%	0.0%	60.9%	25.1%	0.8%	5.5%	1.1%	0.2%	0.8%	4.4%	0.0%	0.1%	0.0%	0.0%	100.0%	
PRIOR YEARS WEEKDAY AADT CLASSIFICATION COUNT																	
003(WDay	EB	162	0	45,962	27,567	860	2,971	783	164	631	3,514	32	102	22	1	82,768	
	WB																82,768

No data available

Table 2. I-80 Traffic Volume Data for Weekends. (NJDOT, 2004)

LOCATION: I-80 , MP 66.2, South Hackensack, Bergen Co.

F.C.= 11

MONTH	DIR	Unclass 0	Motor-cycle 1	Auto 2	2-Axle 4-Tire 3	Bus 4	2-Axle 6-Tire 5	3-Axle 1-Unit 6	4-Axle 1-Unit 7	<=4-Axle 1-Trailer 8	5-Axle 1-Trailer 9	>=6-Axle 1-Trailer 10	<=-Axle 2-Trailer 11	6-Axle 2-Trailer 12	>=7-Axle 2-Trailer 13	MONTHLY ADT EB WB	COMBINE
JAN 2004	EB	403	-	32,003	20,162	128	1,046	269	3	100	1,038	5	42	7	-	55,206	
	WB																
FEB 2004	EB	402	-	36,384	22,090	203	1,004	260	2	118	1,049	7	50	10	-	61,579	
	WB																
MAR 2004	EB	531	-	38,424	22,649	284	1,277	345	20	175	1,455	10	52	16	-	65,238	
	WB																
APR 2004	EB	461	-	35,023	20,325	200	936	246	14	119	961	8	49	8	-	58,350	
	WB																
MAY 2004	EB	525	-	35,274	20,036	233	1,206	231	56	152	1,079	11	53	12	-	58,868	
	WB																
JUN 2004	EB	675	-	41,862	24,042	376	1,525	321	76	159	1,100	14	54	15	-	70,219	
	WB																
JUL 2004	EB	407	-	33,811	19,543	203	1,206	241	67	156	996	11	44	7	-	56,692	
	WB	381	-	53,839	13,714	143	1,808	434	23	157	1,248	13	48	11	-	71,819	128,511
AUG 2004	EB	212	-	41,059	25,595	285	1,235	324	87	167	1,086	14	55	11	-	70,130	
	WB	351	-	52,707	14,408	190	3,229	476	16	182	1,285	8	57	10	-	72,919	143,049
SEP 2004	EB	360	-	44,320	19,621	200	1,157	311	93	152	1,027	8	58	12	-	67,319	
	WB	370	-	53,049	14,326	169	2,893	444	9	171	1,235	8	58	11	-	72,743	140,062
OCT 2004	EB	521	-	49,801	16,499	197	1,236	335	103	163	1,175	13	58	10	-	70,111	
	WB	372	-	51,367	14,664	169	5,478	445	21	204	1,285	9	48	12	-	74,074	144,185
NOV 2004	EB	377	-	39,156	13,649	153	1,097	282	80	139	1,113	8	46	8	-	56,108	
	WB	944	-	48,412	13,540	151	4,871	383	30	232	1,067	5	37	11	-	69,683	125,791
DEC 2004	EB	331	-	45,712	16,329	183	1,292	352	55	156	1,165	11	67	8	-	65,661	
	WB	909	-	46,650	13,530	159	7,170	372	16	175	1,191	7	51	9	-	70,239	135,900
AVERAG	EB	425	0	39,402	20,045	220	1,185	293	55	146	1,104	10	52	10	0	62,948	
	WB	5,673	0	51,004	14,030	164	4,242	426	19	187	1,219	8	50	11	0	74,074	137,022
TOTAL (EB+WB)		6,098	0	90,406	34,075	384	5,426	719	74	333	2,322	18	102	21	0	137,022	
% DAILY	EB	0.7%	0.0%	62.6%	31.8%	0.4%	1.9%	0.5%	0.1%	0.2%	1.8%	0.0%	0.1%	0.0%	0.0%	100.0%	
	WB	7.7%	0.0%	68.9%	18.9%	0.2%	5.7%	0.6%	0.0%	0.3%	1.6%	0.0%	0.1%	0.0%	0.0%	100.0%	
% TOTAL		4.5%	0.0%	66.0%	24.9%	0.3%	4.0%	0.5%	0.1%	0.2%	1.7%	0.0%	0.1%	0.0%	0.0%	100.0%	
PRIOR YEARS WEEKEND AADT CLASSIFICATION COUNT																	
003(WEnd	EB	475	0	36,779	21,820	201	1,188	303	59	133	1,142	7	51	7	0	62,164	
	WB																62,164

(shaded) No data available

Table 3. US Route 9 Traffic Volume Data for Weekdays. (NJDOT, 2004)

LOCATION: US-9 (SB/NB), MP 111.8, Freehold Twp., Monmouth Co.
F.C.= 14

MONTH	DIR	Unclass 0	Motor-cycle 1	Auto 2	2-Axle 4-Tire 3	Bus 4	2-Axle 6-Tire 5	3-Axle 1-Unit 6	4-Axle 1-Unit 7	<=4-Axle 1-Trailer 8	5-Axle 1-Trailer 9	>=6-Axle 1-Trailer 10	<=-Axle 2-Trailer 11	6-Axle 2-Trailer 12	>=7-Axle 2-Trailer 13	MONTHLY ADT NB SB	MONTHLY ADT COMBINE
JAN 2004	NB	170	-	13,041	9,025	154	1,053	168	15	44	176	1	2	-	-	23,849	
	SB																
FEB 2004	NB	126	-	14,141	10,149	193	1,272	176	30	53	193	1	3	-	-	26,337	
	SB																
MAR 2004	NB	95	-	14,782	10,080	217	1,064	207	17	63	222	4	2	-	-	26,753	
	SB																
APR 2004	NB	112	-	15,503	10,348	190	1,043	205	18	72	226	3	2	-	-	27,722	
	SB																
MAY 2004	NB	125	-	15,873	10,318	202	1,022	214	70	73	229	4	2	-	-	28,132	
	SB																
JUN 2004	NB	123	-	16,515	10,804	208	1,061	229	110	84	238	4	2	-	-	29,378	
	SB																
JUL 2004	NB															28,311	
	SB																
AUG 2004	NB															28,044	
	SB																
SEP 2004	NB															26,260	
	SB																
OCT 2004	NB	103	-	14,728	10,168	205	1,087	192	26	68	206	4	2	-	-	26,789	
	SB																
NOV 2004	NB	115	-	14,507	10,087	156	982	218	34	57	199	4	2	-	-	26,361	
	SB																
DEC 2004	NB	100	-	13,229	10,277	191	1,758	165	10	69	187	5	3	-	-	25,994	
	SB																
AVERAGI	NB	119	0	14,702	10,140	191	1,149	197	37	65	208	3	2	0	0	26,813	
	SB																
TOTAL (NB+SB)		119	0	14,702	10,140	191	1,149	197	37	65	208	3	2	0	0	26,813	
% DAILY	NB	0.4%	0.0%	54.8%	37.8%	0.7%	4.3%	0.7%	0.1%	0.2%	0.8%	0.0%	0.0%	0.0%	0.0%	100.0%	
	SB																
% TOTAL		0.4%	0.0%	54.8%	37.8%	0.7%	4.3%	0.7%	0.1%	0.2%	0.8%	0.0%	0.0%	0.0%	0.0%	100.0%	
PRIOR YEARS WEEKDAY AADT CLASSIFICATION COUNT																	
003(WDay	NB	74	0	15,634	9,856	141	1,154	191	12	56	192	3	2	0	0	27,315	
	SB															27,749	55,064
002(WDay	NB	60	0	22,280	4,902	278	946	145	16	80	228	7	2	0	0	28,946	
	SB																28,946

No data available

Table 4. US Route 9 Traffic Volume Data for Weekends. (NJDOT, 2004)

LOCATION: US-9 (SB/NB), MP 111.8, Freehold Twp., Monmouth Co.

F.C.= 14

MONTH	DIR	Unclass	Motor-cycle	Auto	2-Axle 4-Tire	Bus	2-Axle 6-Tire	3-Axle 1-Unit	4-Axle 1-Unit	<=4-Axle 1-Trailer	5-Axle 1-Trailer	>=6-Axle 1-Trailer	<=-Axle 2-Trailer	6-Axle 2-Trailer	>=7-Axle 2-Trailer	MONTHLY ADT NB SB	COMBINE
		0	1	2	3	4	5	6	7	8	9	10	11	12	13		
JAN 2004	NB	83	-	12,728	8,349	26	599	69	-	5	47	-	-	-	-	21,906	
	SB																
FEB 2004	NB	33	-	13,829	8,911	18	607	69	-	6	48	-	-	-	-	23,521	
	SB																
MAR 2004	NB	64	-	14,696	8,648	19	576	71	-	9	53	-	1	-	-	24,137	
	SB																
APR 2004	NB	34	-	12,514	7,926	19	470	76	3	15	48	1	-	-	-	21,106	
	SB																
MAY 2004	NB	39	-	14,734	9,335	19	508	89	1	23	63	1	-	-	-	24,812	
	SB																
JUN 2004	NB	41	-	14,933	9,293	22	547	92	3	17	69	1	-	-	-	25,018	
	SB																
JUL 2004	NB																
	SB																
AUG 2004	NB																
	SB																
SEP 2004	NB	12	-	14,242	8,838	3	182	35	-	1	13	-	-	-	-	23,326	
	SB																
OCT 2004	NB	42	-	13,898	9,506	19	558	91	8	17	57	1	-	-	-	24,197	
	SB																
NOV 2004	NB	50	-	13,609	8,801	17	604	95	17	15	61	-	-	-	-	23,269	
	SB																
DEC 2004	NB	62	-	14,053	9,576	22	975	73	2	11	55	1	-	-	-	24,830	
	SB																
AVERAG	NB	46	0	13,924	8,918	18	563	76	3	12	51	1	0	0	0	23,612	
	SB																
TOTAL (NB+SB)		46	0	13,924	8,918	18	563	76	3	12	51	1	0	0	0	23,612	
% DAILY	NB	0.2%	0.0%	59.0%	37.8%	0.1%	2.4%	0.3%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	100.0%	
	SB																
% TOTAL		0.2%	0.0%	59.0%	37.8%	0.1%	2.4%	0.3%	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	100.0%	
PRIOR YEARS WEEKEND AADT CLASSIFICATION COUNT																	
003(WEnd	NB	78	0	14,169	7,786	16	700	72	1	10	48	0	0	0	0	22,880	
	SB															24,245	47,125
002(WEnd	NB	50	0	19,225	4,615	60	554	41	1	13	52	0	0	0	0	24,611	
	SB																24,611

No data available

Table 5. Average Daily Traffic for 2004 for US Route 9 and I-80. (NJDOT, 2004)

Vehicle Type and Travel Day		**US Route 9**		**I-80**	
		NB	SB*	EB	WB
Auto	Weekdays	14,702	-	47,692	59,937
	Weekends	13,924	-	39,402	51,004
Two-Axle	Weekdays	11,289	-	29,044	25,135
	Weekends	9,481	-	21,230	18,272
Five-Axle	Weekdays	208	-	3,496	4,239
	Weekends	51	-	1,104	1,219
AADT	Weekdays	26,813	-	83,916	92,714
	Weekends	23,612	-	62,948	74,074
Total AADT (weekdays)		53626*		176,630	

* NJDOT traffic counts for Route 9 southbound were not available.
Northbound and southbound traffic counts were assumed similar.
NB = northbound, SB = southbound

Table 6. Approximate Costs of Road Closure and Pipe Replacement.

Item	**US Route 9**		**I-80**	
	Full Closure (Three Lanes)*	Partial Closure (One Lane)**	Full Closure (Three Lanes)*	Partial Closure (One Lane)**
Cost of Damaged Pipe Removal and Installation of New Pipe (36 in pipe)	$60,000	$60,000	$60,000	$60,000
Cost Incurred due to Traffic Delays and Traffic Diversion (5 days)	$3,500,000	$1,150,000	$6,000,000	$2,000,000
Total Cost	$3,560,000	$1,210,000	$6,060,000	$2,060,000

* Full closure of traffic in one direction
** Partial closure (one lane) in one direction

Figure 1. Traffic on I-80 near Exit 38.

Figure 2. Traffic on US Route 9.

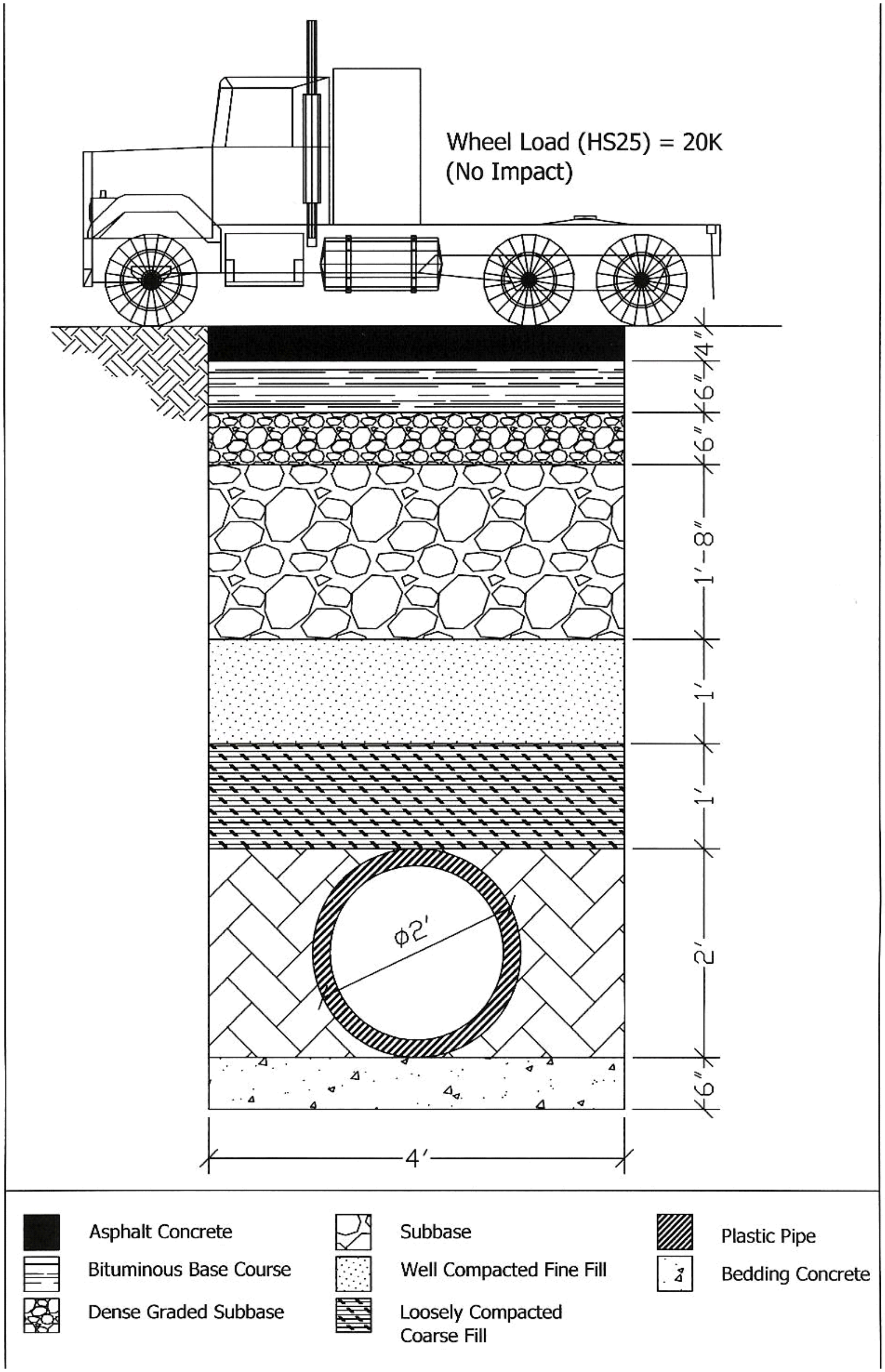


Figure 3. Roadway section for 24-in diameter pipe.

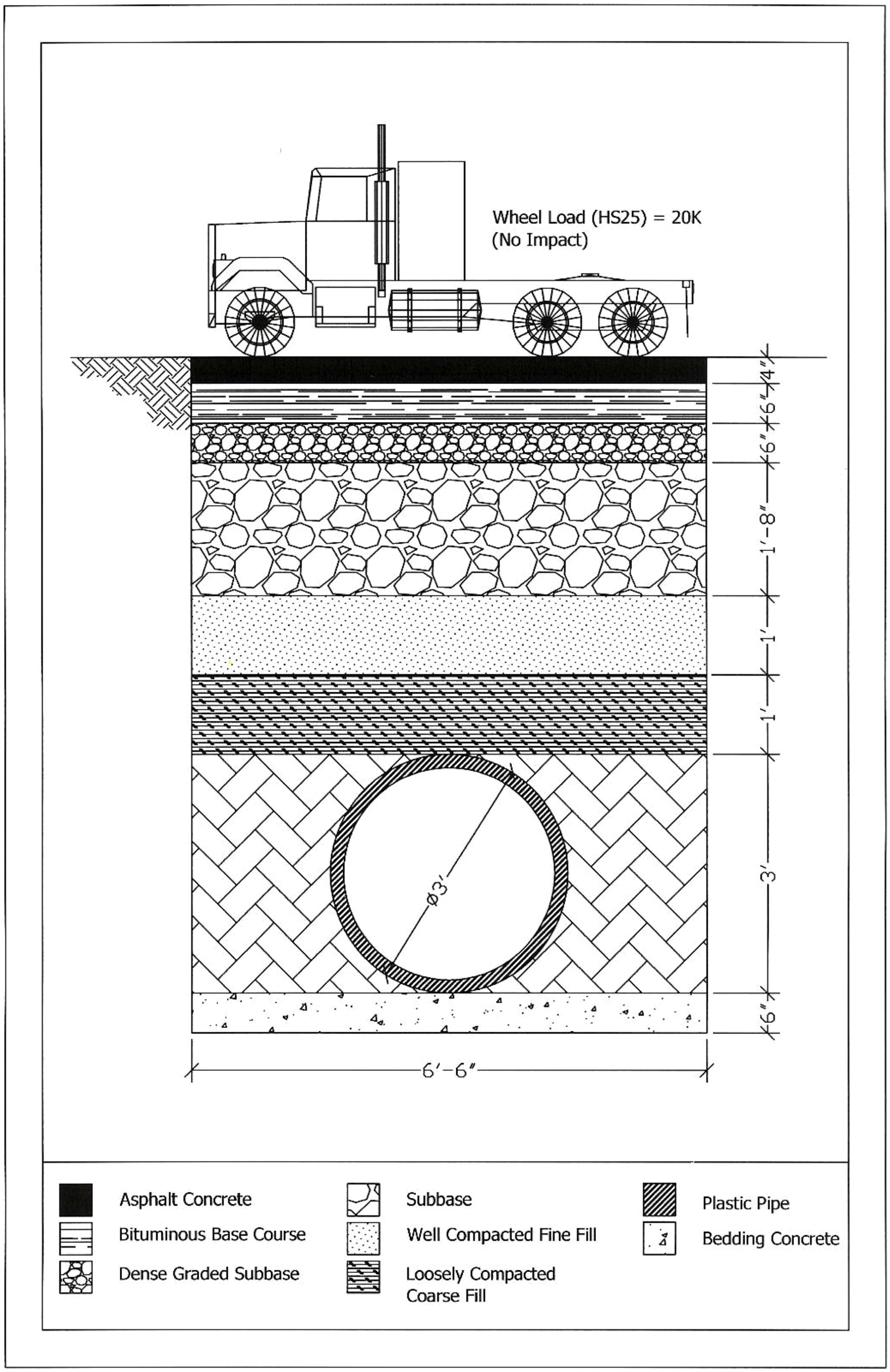


Figure 4. Roadway section for 36-in diameter pipe.

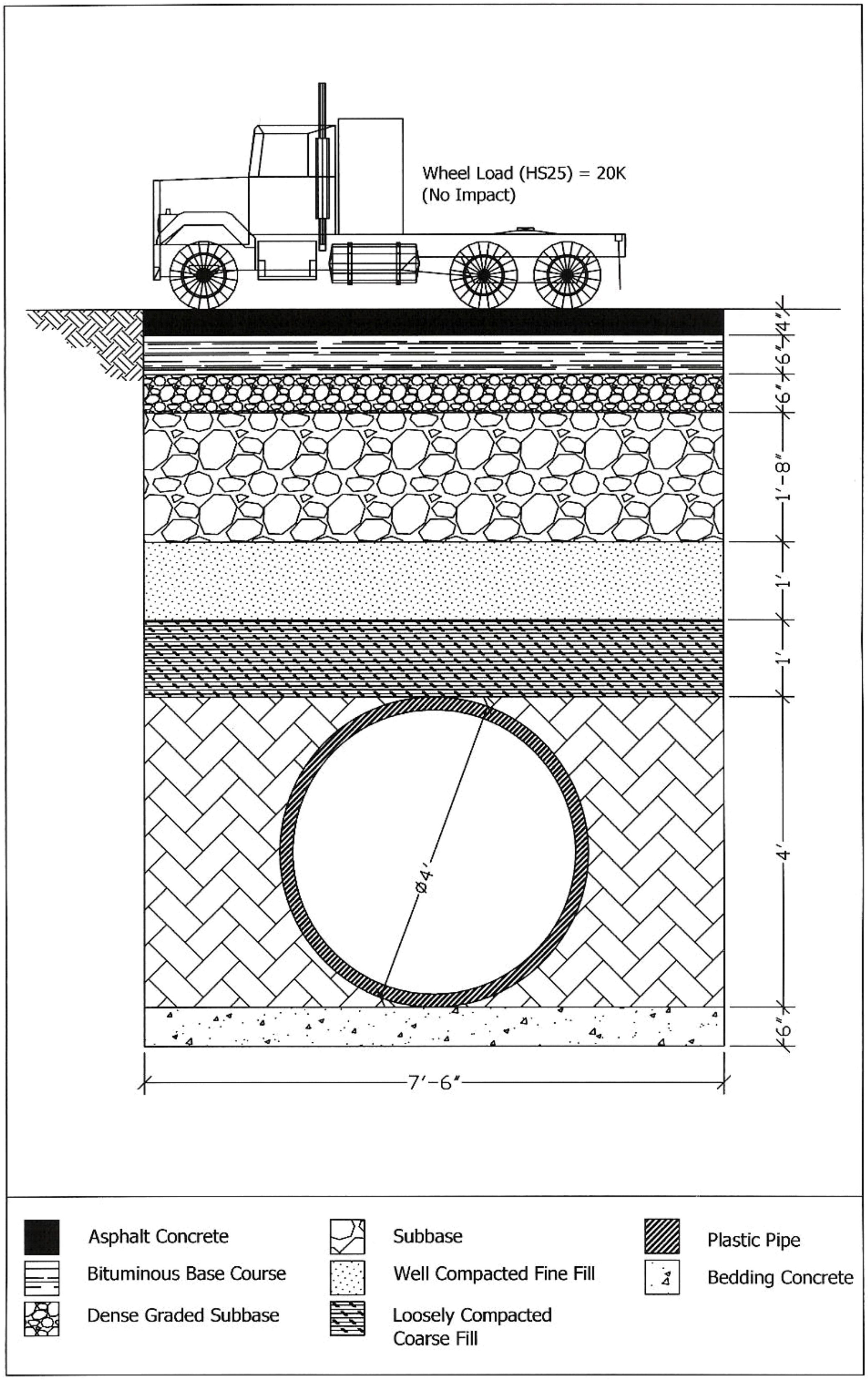


Figure 5. Roadway section for 48-in diameter pipe.

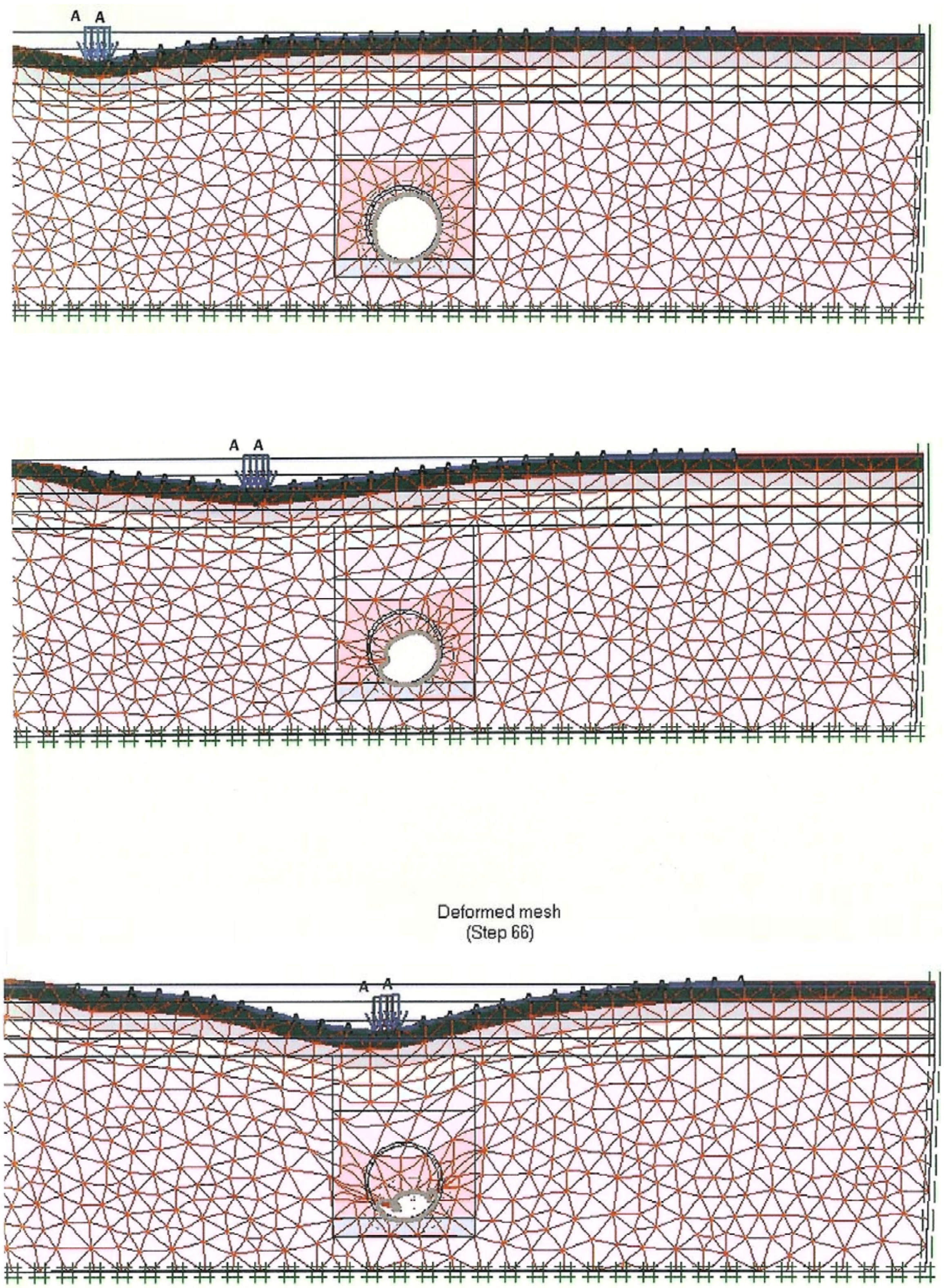


Figure 6. Progressive collapse of roadway surface for 24-in diameter buried pipe.

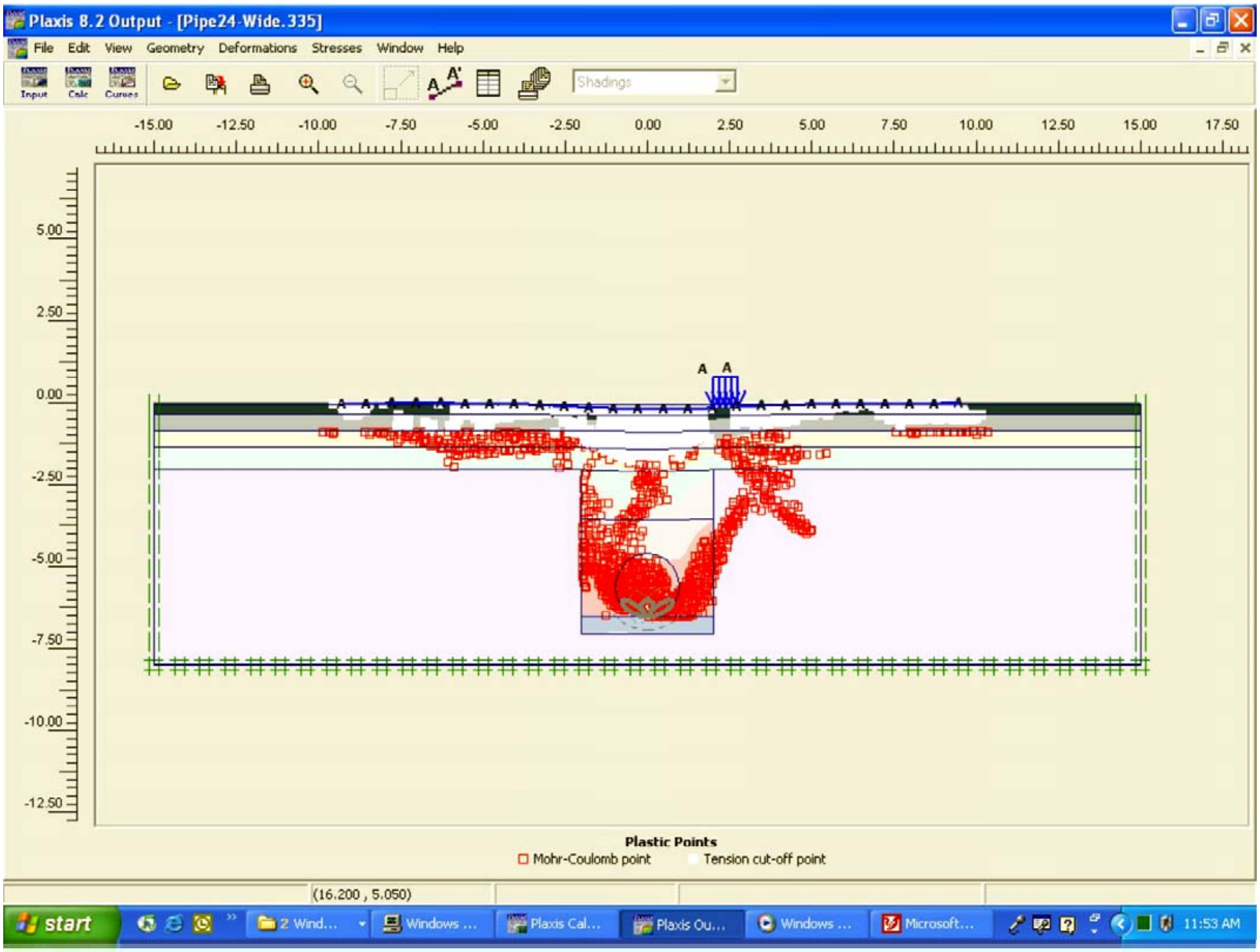


Figure 7. Soil plastification (damage) for the 24-in diameter pipe.

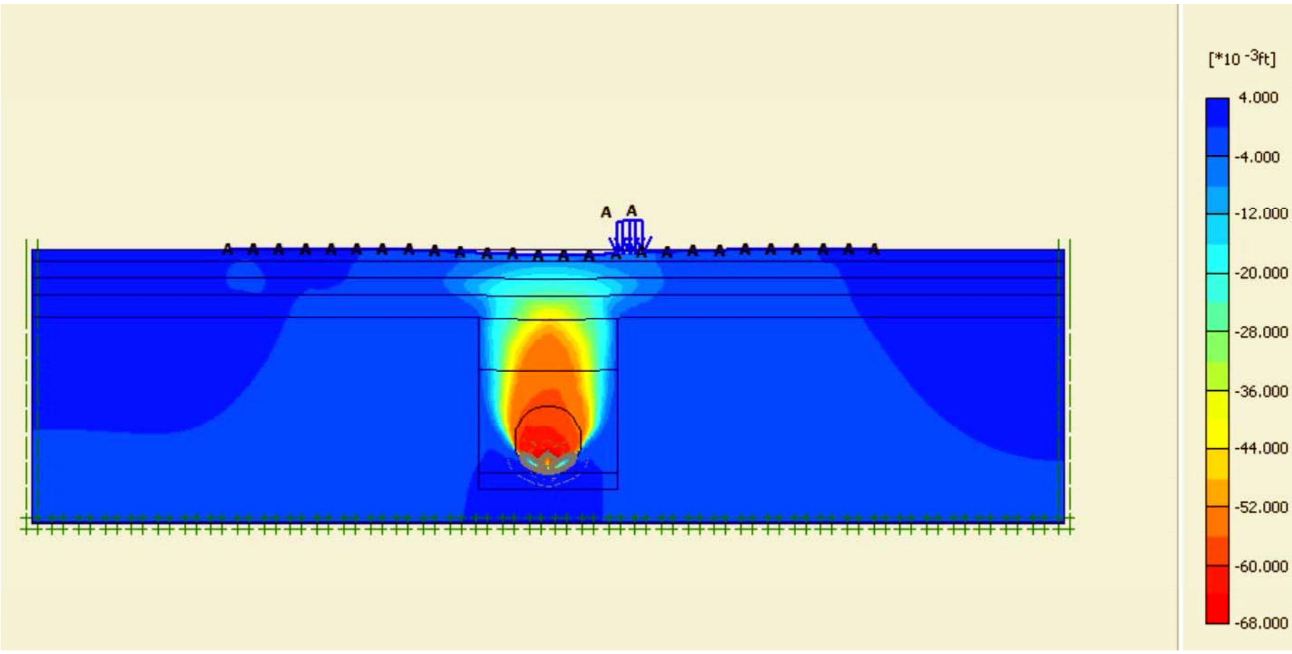


Figure 8. Vertical displacements in soil for 24-in diameter pipe.

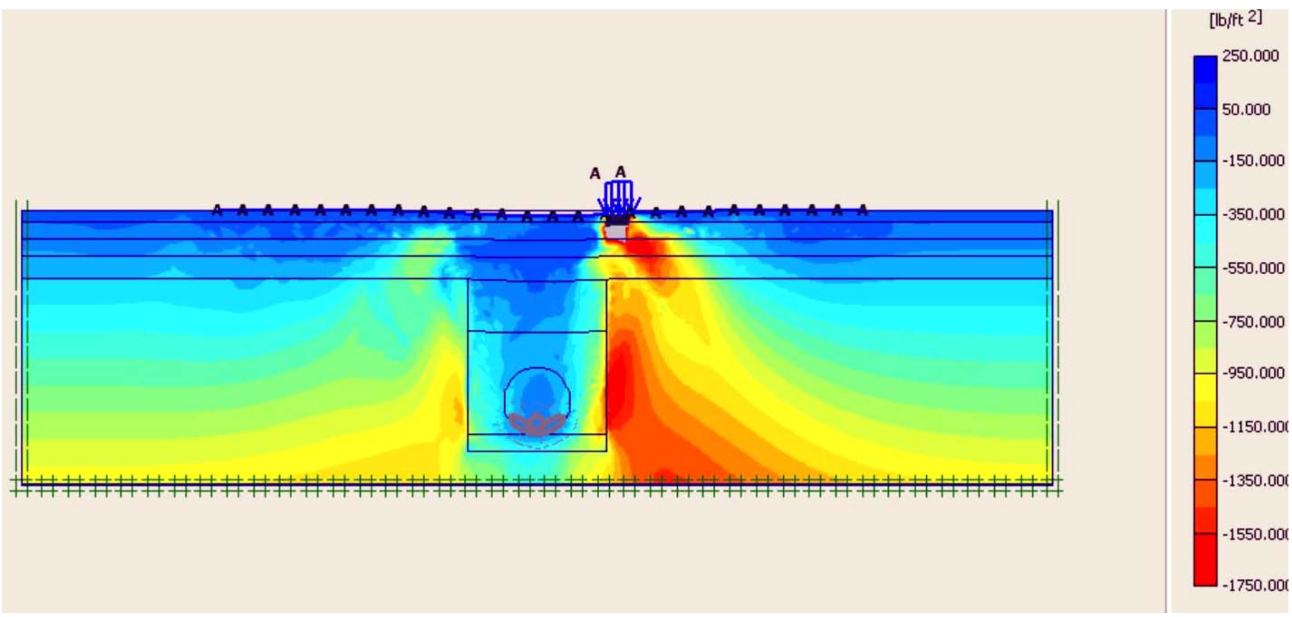


Figure 9. Vertical stresses in soil for 24-in diameter pipe.

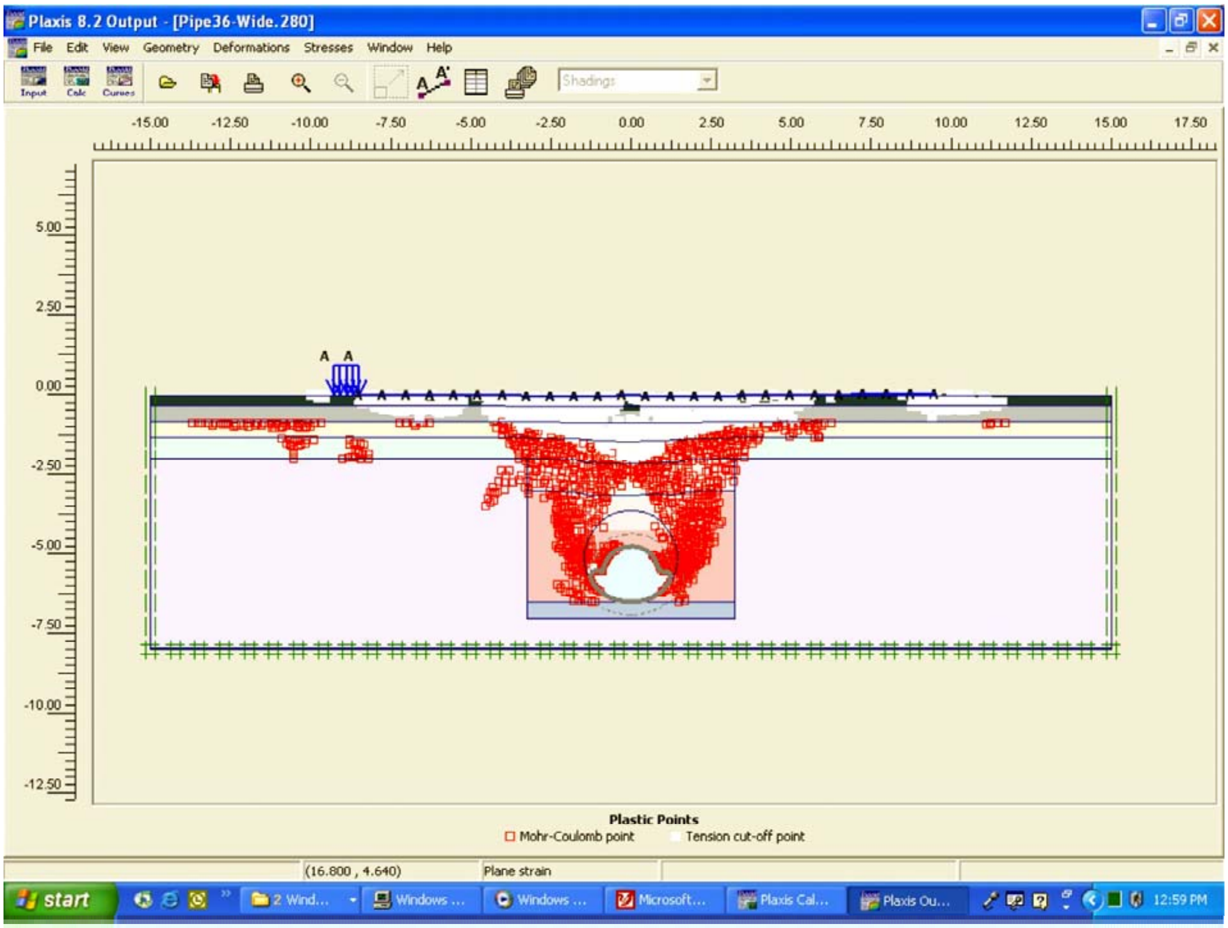


Figure 10. Soil plastification (damage) for the 36-in diameter pipe.

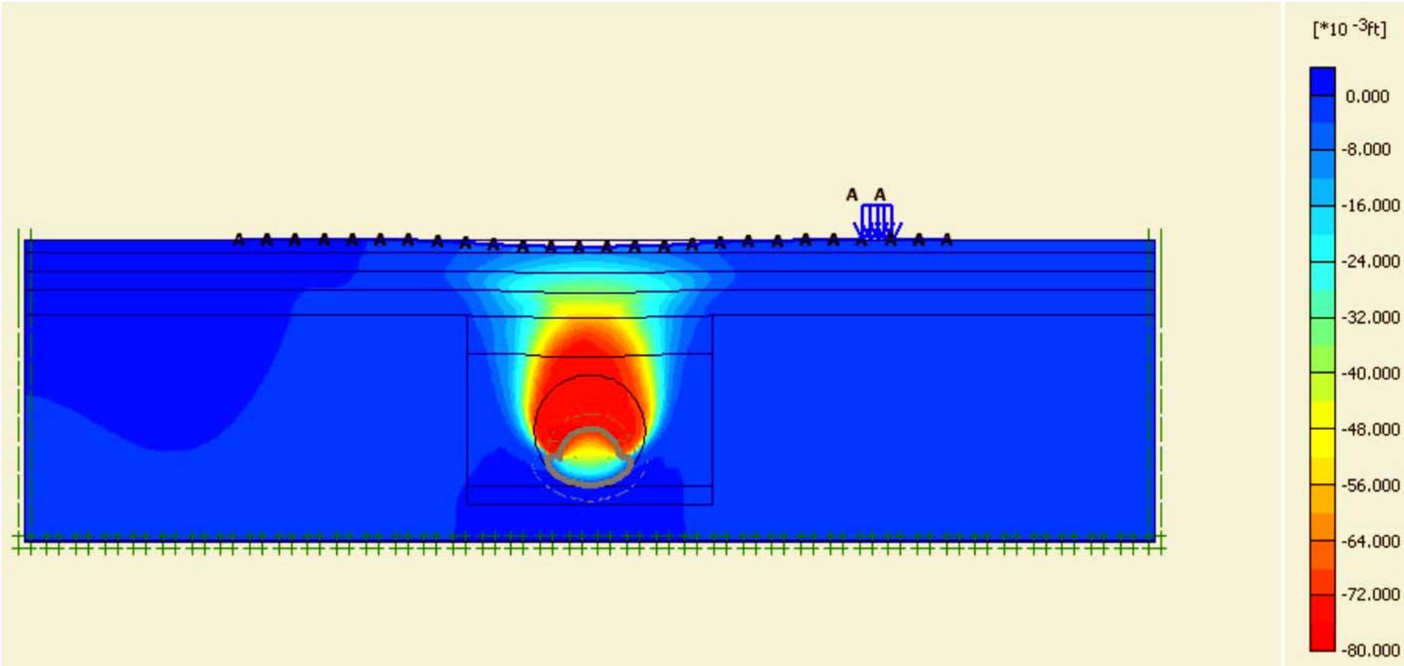


Figure 11. Vertical displacements in soil for 36-in diameter pipe.

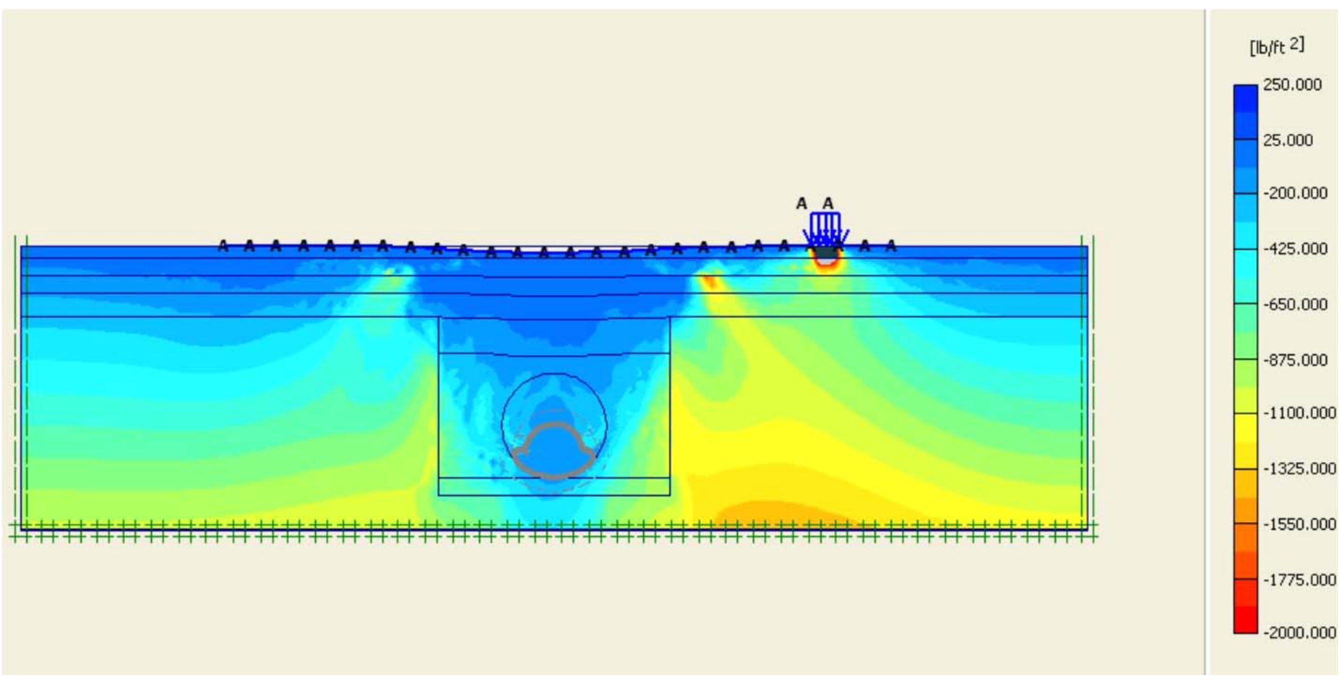


Figure 12. Vertical stresses in soil for 36-in diameter pipe.

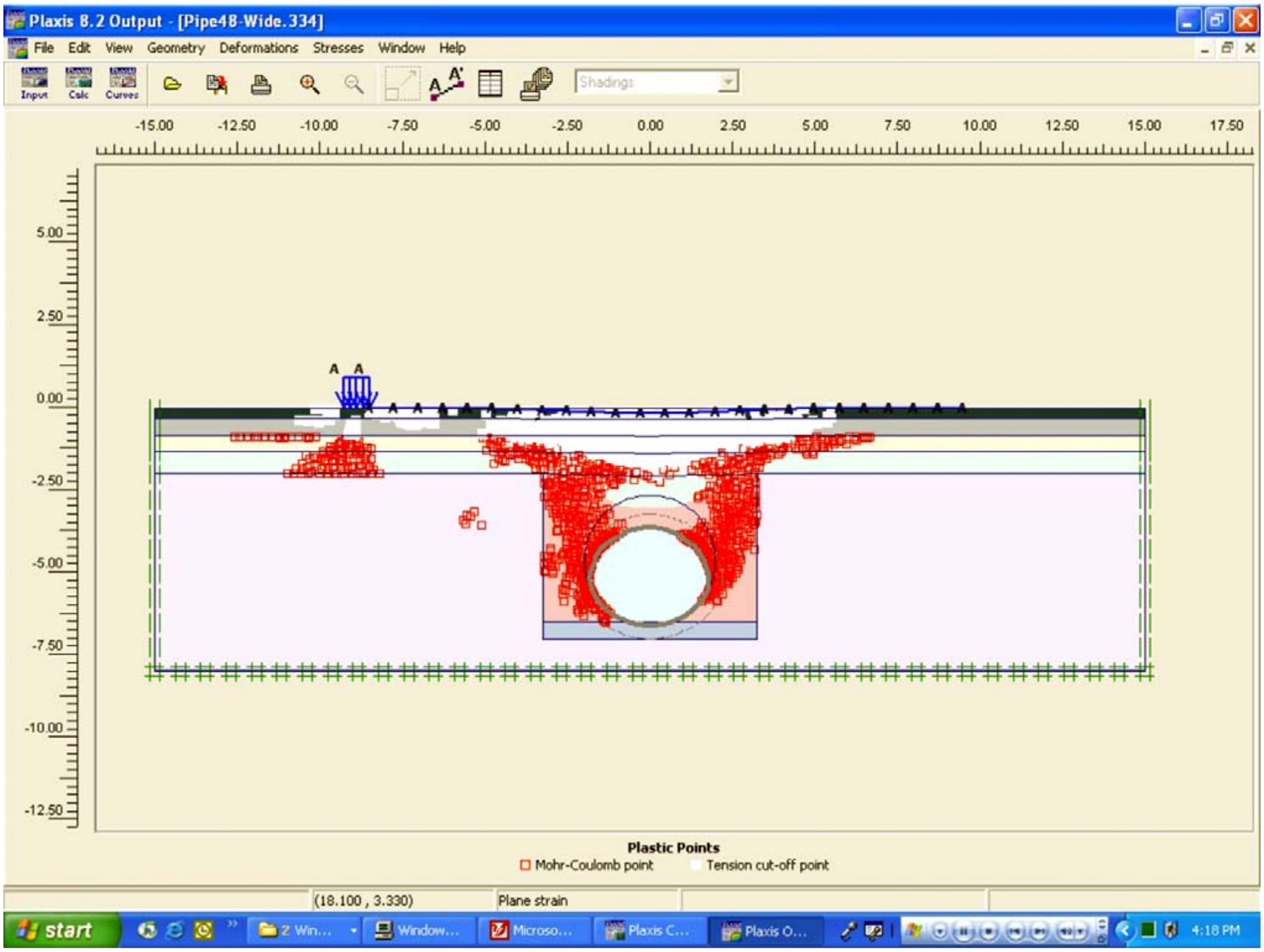


Figure 13. Soil plastification (damage) for the 48-in diameter pipe.

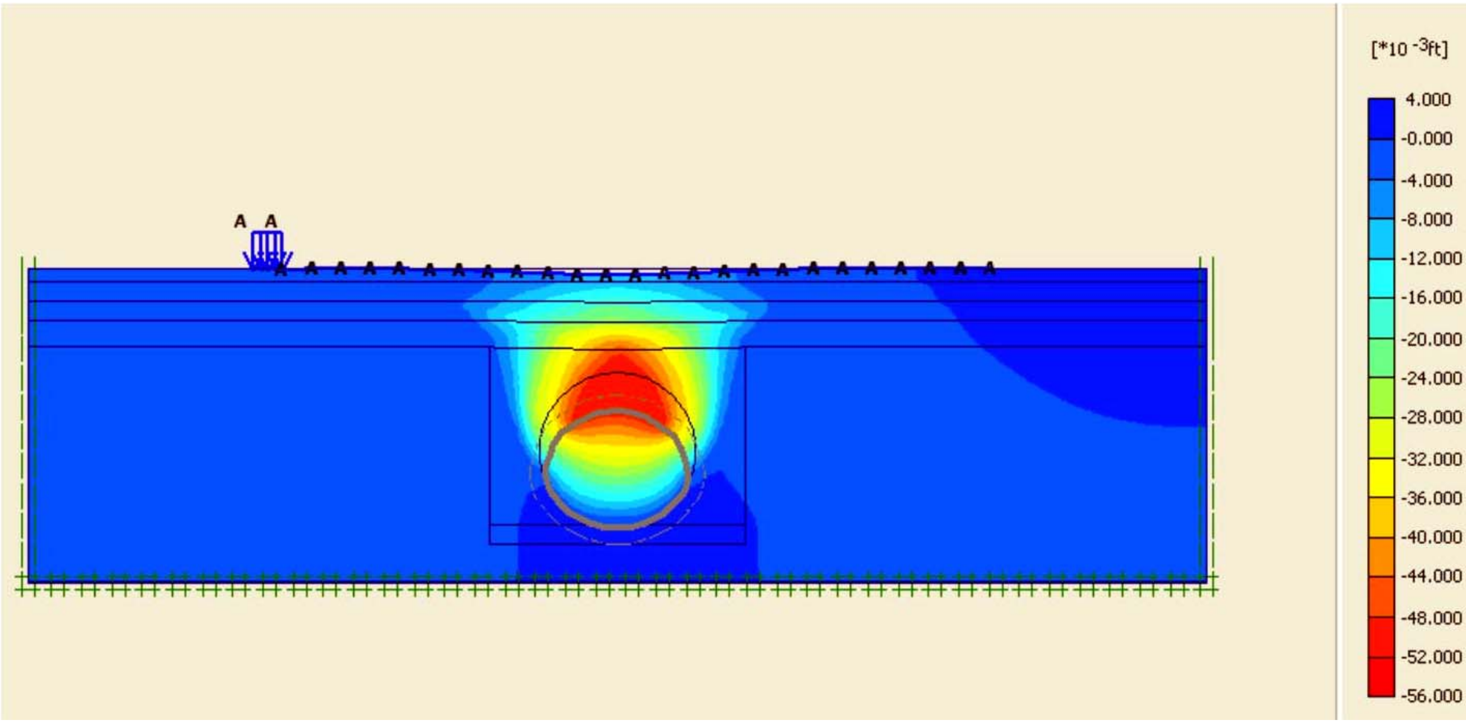


Figure 14. Vertical displacements in soil for 48-in diameter pipe.

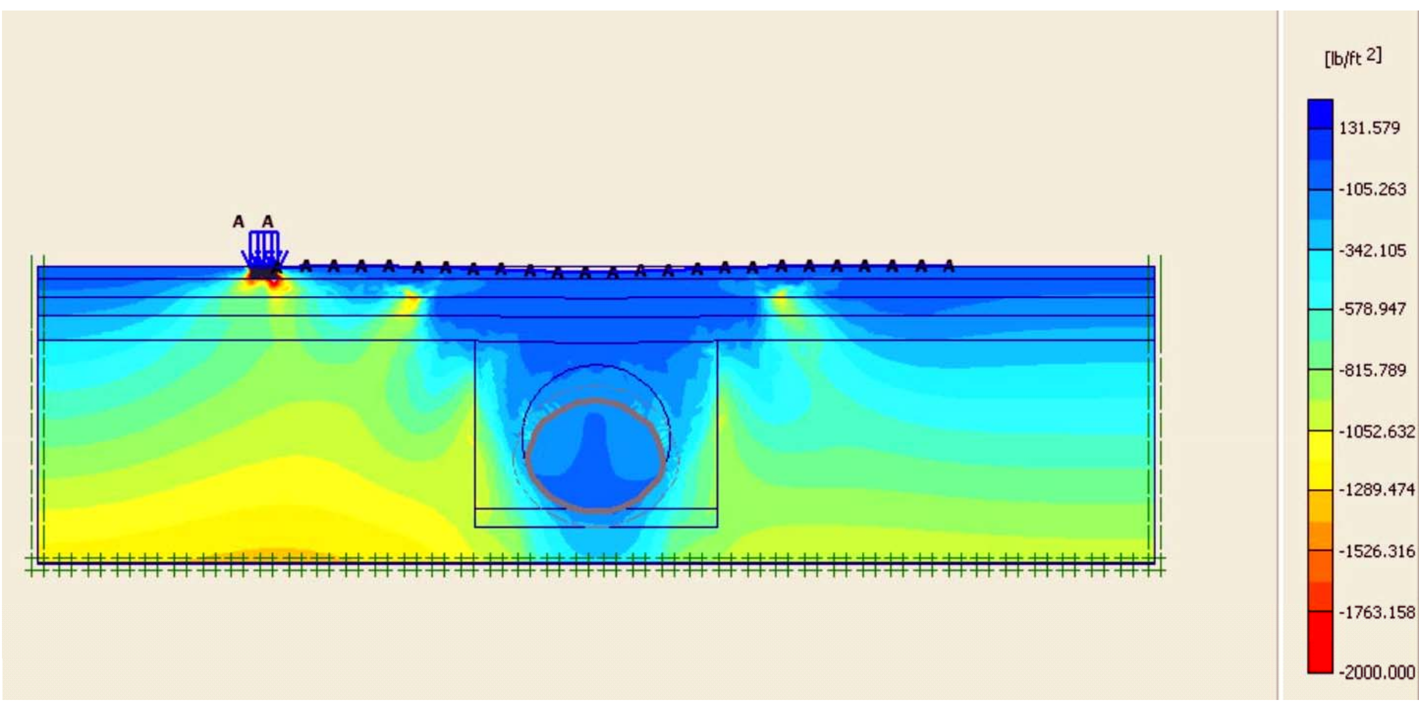


Figure 15. Vertical stresses in soil for 48-in diameter pipe.

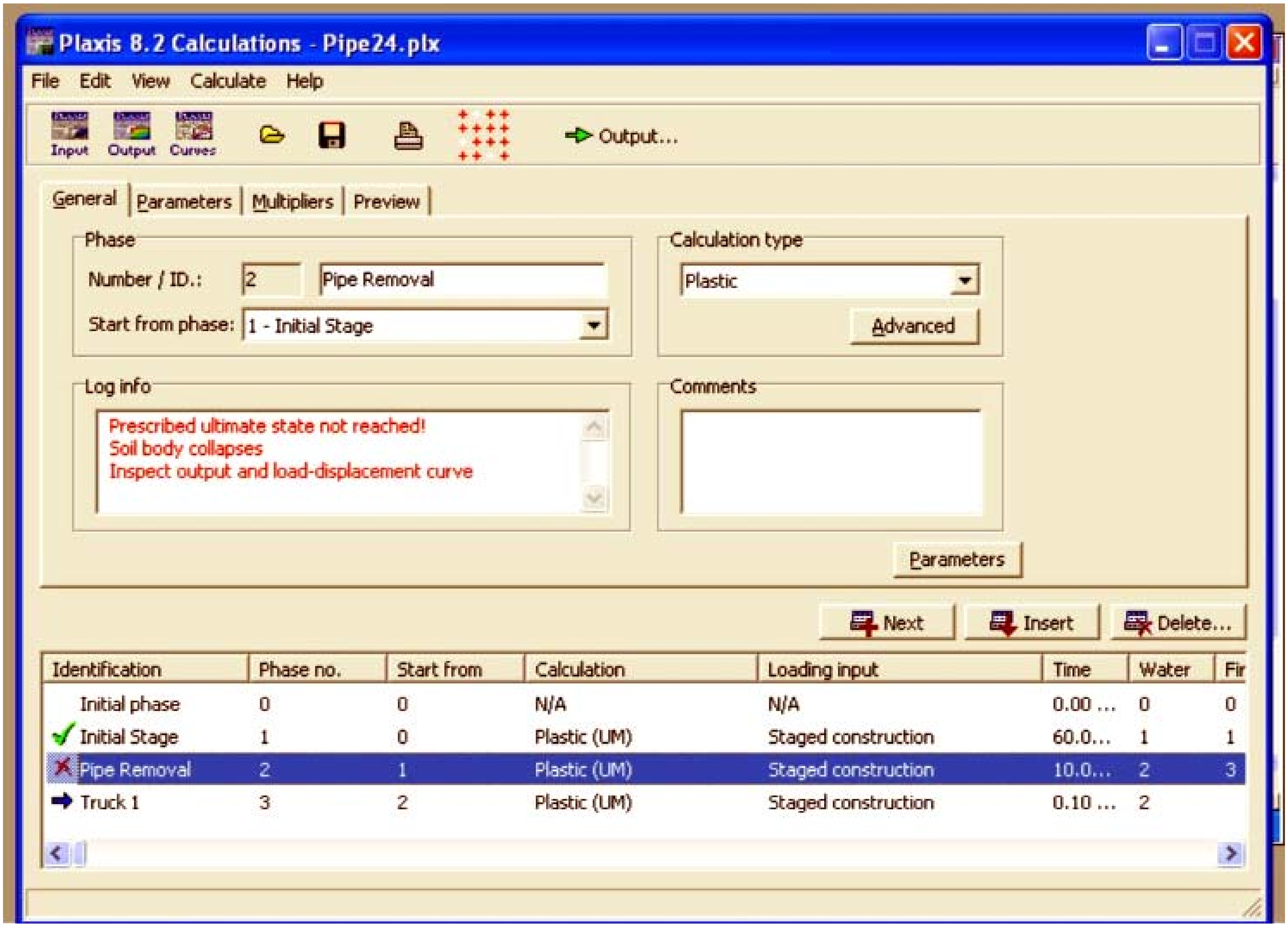


Figure 16. Typical program run screen showing log information that indicated the soil body collapsed.