

Hydroconsolidation (Collapse) Case History

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Introduction

Hydroconsolidation, commonly referred to as soil collapse, is a common problem in southern California. Hydroconsolidation typically occurs in recent soil materials that were deposited in arid or semi-arid environments. Collapsible soils in southern California are commonly associated with alluvial fan and mudflow sediments deposited during flash floods. The soils contain minute pores and voids (sometimes visible without magnification), and soil particles may be partially supported by clay or silt, or chemically cemented with carbonates. When wetted, collapsible soils undergo a rearrangement of their grains and the water removes the cementing material, causing rapid, significant settlement (Figure 1). Common causes of the wetting are surface infiltration (such as from irrigation or a leak), water ponded at the surface, or a rise in the groundwater table. When significant amounts of water are introduced into the soil materials from the surface, the collapse settlements can be amplified and supplemented by consolidation settlement induced by the significant increases in soil unit weight resulting from the addition of water.

Collapse of Microstructure

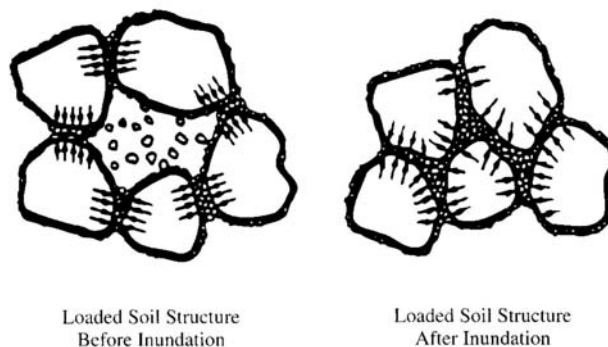


Figure 1 - Illustration of collapsible soil structure

The case history described herein occurred at a semi-rural site located in southern California. To protect the privacy of the involved parties, the site location will not be disclosed and details of the site conditions presented herein are generalized. The hydroconsolidation-modeling capabilities of *Settle^{3D}* were used to estimate settlements and the results were found to compare well with site observations.

Site Development

The site was initially explored for development in 1994, at which time four hollow-stem-auger borings were drilled to determine site soil conditions and to obtain samples for laboratory testing. From that exploration, the geotechnical consultant determined that there were visibly porous, collapsible alluvial soil materials on the site and from several single-oedometer laboratory collapse tests (Figure 2), he estimated collapse strains ranging from about 0.2 to 2.8 percent. Because the soil layers that showed the most collapse potential were located within the upper 2 to 5 feet of the soil profile, the geotechnical consultant removed and recompacted the native soil materials to a depth of about 6 feet before the large two-story single-family home was constructed on the site in 1995. Between about 2004 to 2006, additional improvements were made to the site, which apparently included the addition of a large patio entertainment area at the rear of the residence.

Single Oedometer Tests

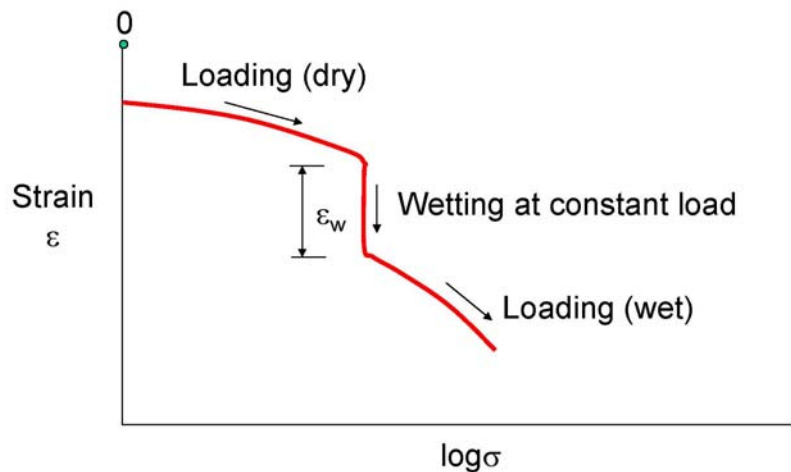


Figure 2 - Schematic diagram of single oedometer collapse test

Water Leaks

In about mid-2006, the residents at the site began to notice a “darkened area” on the surface of the patio slab that was later determined to be caused by water leaking from a broken pressurized pipeline beneath the slab. Water-use records from 2002 through 2008 (Figure 3), indicate that water consumption on the property approximately doubled at about the time the patio leak developed and remained at that higher rate throughout the latter half of 2006 and into the beginning of 2007. Ownership of the property changed near the end of 2006 and the new property owner located and repaired the patio leak in the early part of 2007. However, by that time, a considerable amount of water had entered the collapsible soil materials beneath the site and signs of significant collapse settlement had become apparent in the rear portion of the residential structure.

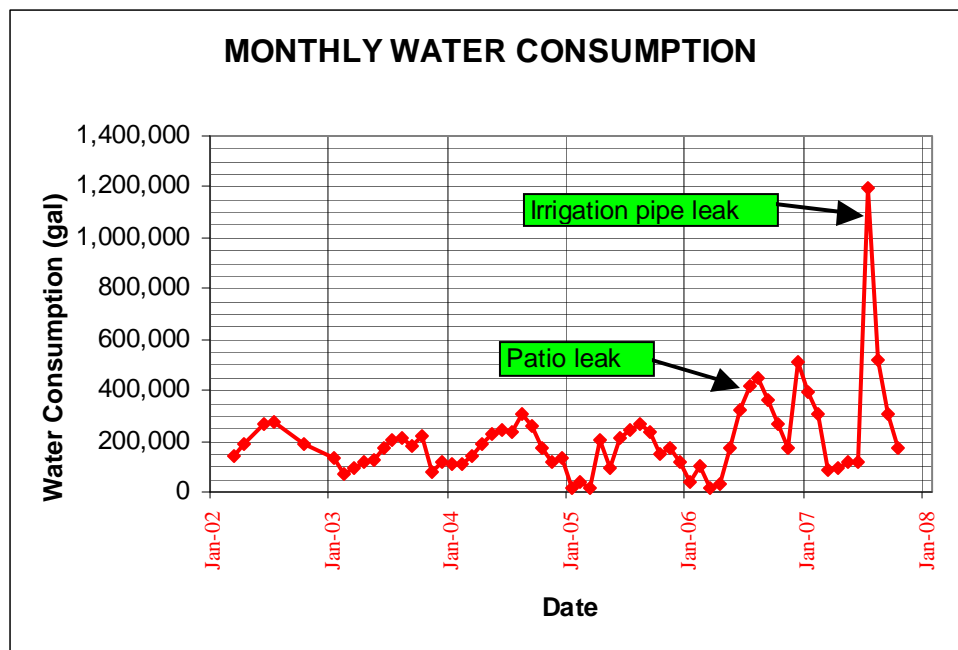


Figure 3 - Water consumption data

When it became apparent that the collapse settlements were continuing to damage the home, as the subsurface water plume was still migrating away from the now-repaired leak area, the owner hired a contractor to install specialized, deep underpinning-elements (jacked-in-place pipe piles) to support the residence and limit the extent of the damaged area. Before the underpinning process could be completed, the migrating subsurface water plume from the patio leak caused enough collapse settlement that another pipeline (a large irrigation line) was broken in the backyard area. That irrigation pipe break resulted in the release of about a million gallons of water (weighing about 10 million pounds) into the soil, during a one month time period, effectively increasing the total unit weight of the soil. If it were not for the underpinning work that was nearly completed by that time, the increased weight and resulting settlement probably would have caused significant additional damage to the home.

Forensic Study

To evaluate and quantify the geotechnical causes of the observed distress, a forensic geotechnical study was commissioned by the homeowner. Several Cone Penetrometer Tests (CPT) were performed to map the subsurface stratigraphy and additional borings were drilled to collect samples for laboratory testing. The forensic geotechnical study developed the generalized subsurface stratigraphy and soil properties shown on Figure 4. Comparisons between soil unit weights measured when the property was developed in 1994 and those obtained after the significant leaks of 2006 and 2007 demonstrated an approximately 10 to 12 pcf increase in the soil's total unit weight (presumably the result of the water infiltration). Numerous single-odometer collapse tests performed for the forensic

studies found that most of the tested soils had very little remaining collapse potential. Therefore, to model pre-collapse site conditions, the forensic study utilized the average collapse test results obtained below a depth of about 5 feet from the pre-development studies (an average of about 0.725 percent).

DEPTH	MATERIAL	DRY UNIT WT.	WET UNIT WT.	Cec	Collapse
0 - 6'	Compacted fill	105 pcf	115 pcf	0	0
6' - 16'	Clayey silt (ML) alluvium	95 pcf	105 pcf	0.22	0.725%
16' - 26'	Clayey silt (MH) alluvium	95 pcf	105 pcf	0.30	0.725%
26' - 46'	Clayey silt (ML) alluvium	100 pcf	110 pcf	0.25	0.725%
46' - 66'	Silty sand alluvium (SM)	100 pcf	110 pcf	0.10	0.600%
66' - 93'	Clayey silt (ML) alluvium	105 pcf	115 pcf	0.25	0.725%
> 93'	Bedrock (weak sandstone)	120 pcf	125 pcf	0	0

Figure 4 - Generalized site stratigraphy

Analysis of Data

To model the observed settlement at the site, Rocscience's *Settle^{3D}* computer program was used. A model consisting of four stages was created:

- Stage 1 - Initial house foundation loading,
- Stage 2 - Collapse zone from patio-pipe break, infiltration 25-feet deep,
- Stage 3 - Collapse zone from patio-pipe-break, infiltration 50-feet deep,
- Stage 4 - Collapse zone from irrigation-pipe-break, infiltration 93-feet deep.

Initially, that model was run using only hydroconsolidation soil properties to estimate the settlement (i.e., the effect of consolidation settlement caused by the increased total unit weight of the soil was neglected). Even assuming that the water leaks saturated the entire 93-foot-thick soil column, from the ground surface to the depth of the underlying bedrock, hydroconsolidation estimates alone (Figures 5a through 5d) were able to account for only about 7 to 8 inches of the observed settlement, which was only about half of the settlement noted at this site.

Therefore, the analysis was repeated by including the additional consolidation settlement that would result from a 10 pcf increase in unit weight. The result was a combined collapse and consolidation settlement estimate of about 16 inches (Figures 6a through 6d). Although no quantitative settlement measurements were ever made at the site, the combined settlement estimate of about 16 inches is believed to be consistent with the magnitude of the distress observed at the site.

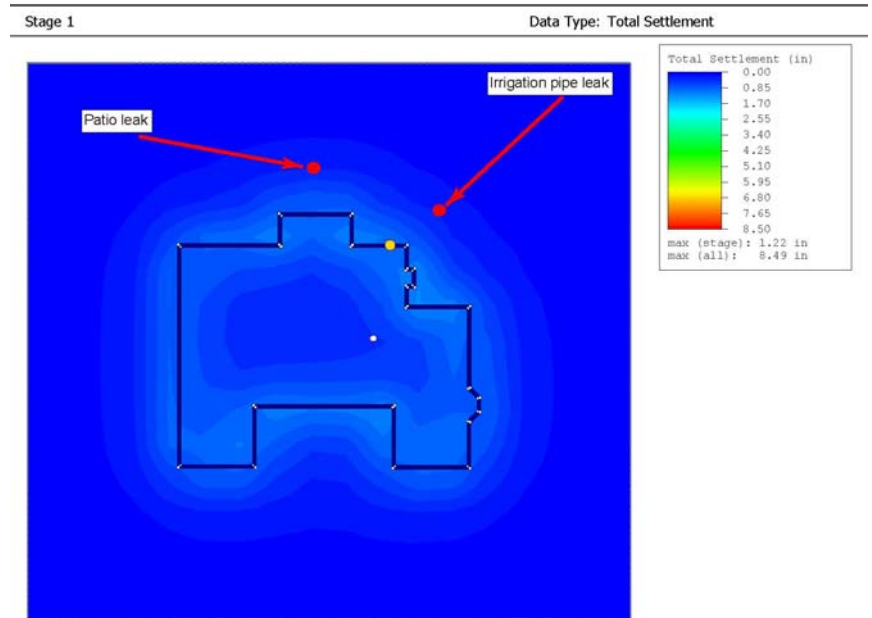


Figure 5a - Stage 1 - Settlement caused by hydroconsolidation settlement only

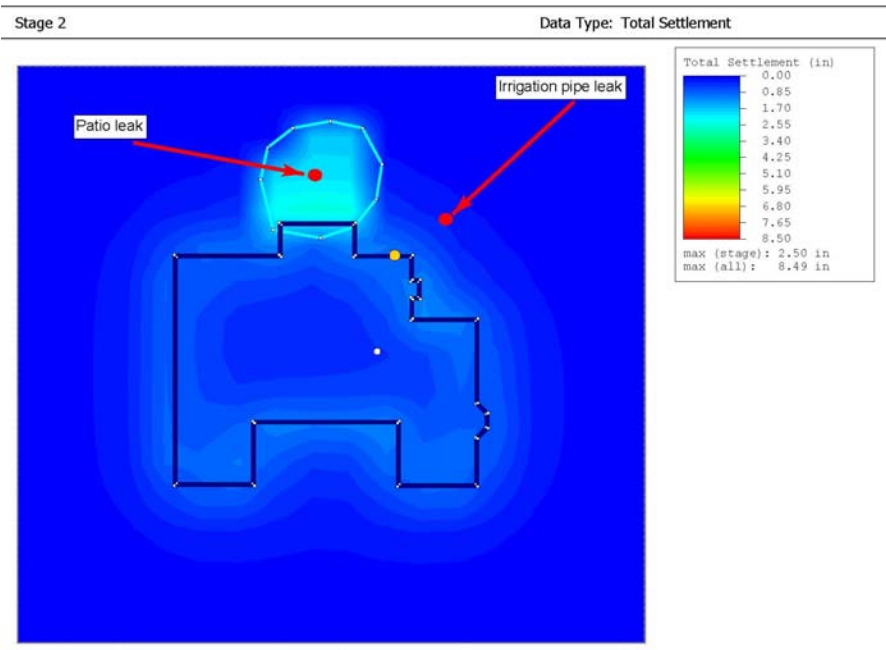


Figure 5b - Stage 2 - Settlement caused by hydroconsolidation settlement only

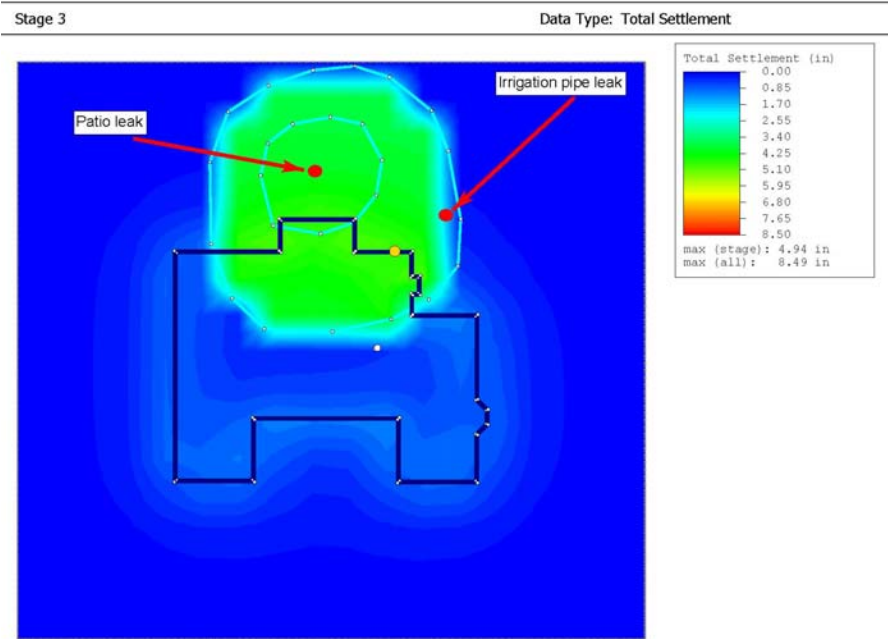


Figure 5c - Stage 3 - Settlement caused by hydroconsolidation settlement only

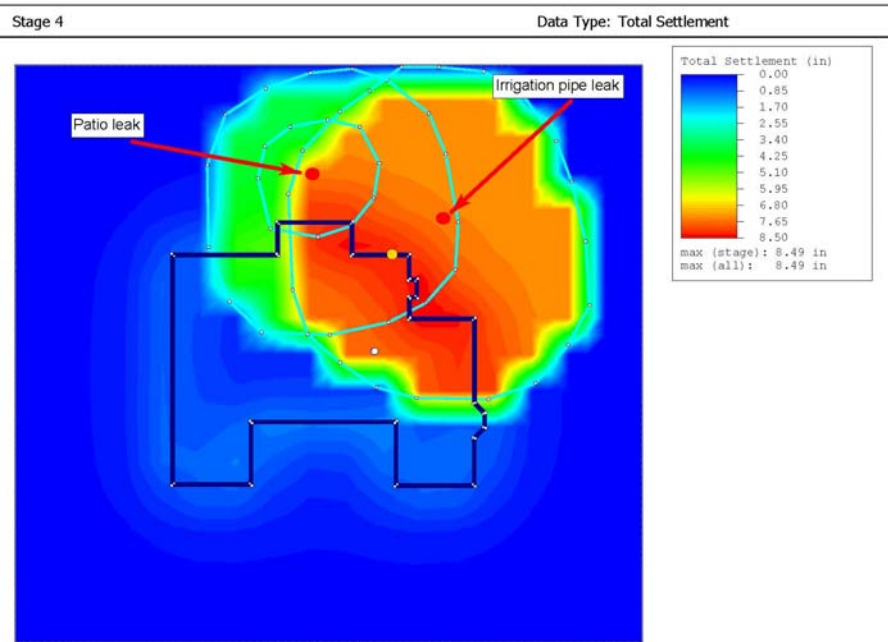


Figure 5d - Stage 4 - Settlement caused by hydroconsolidation settlement only

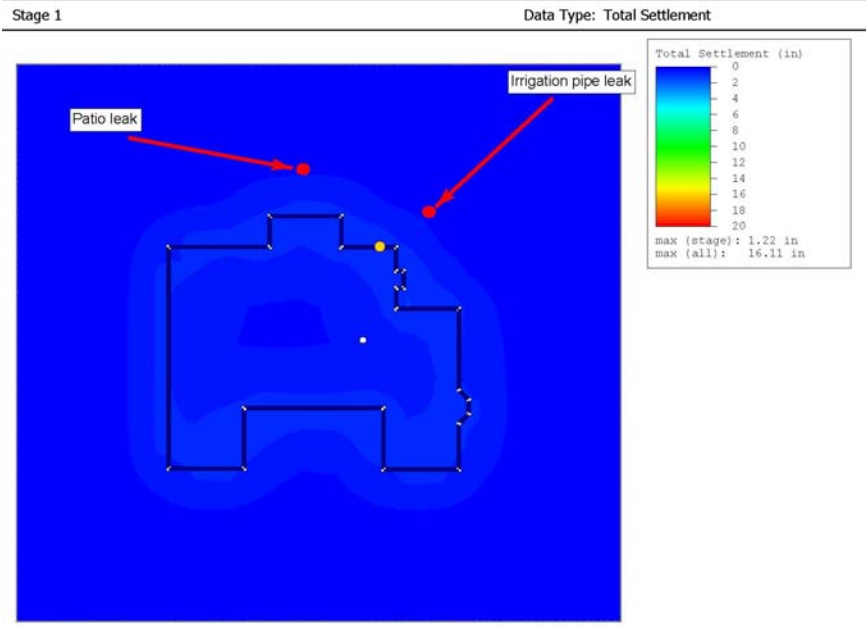


Figure 6a - Stage 1 - Settlement caused by both hydroconsolidation settlement and consolidation settlement, combined

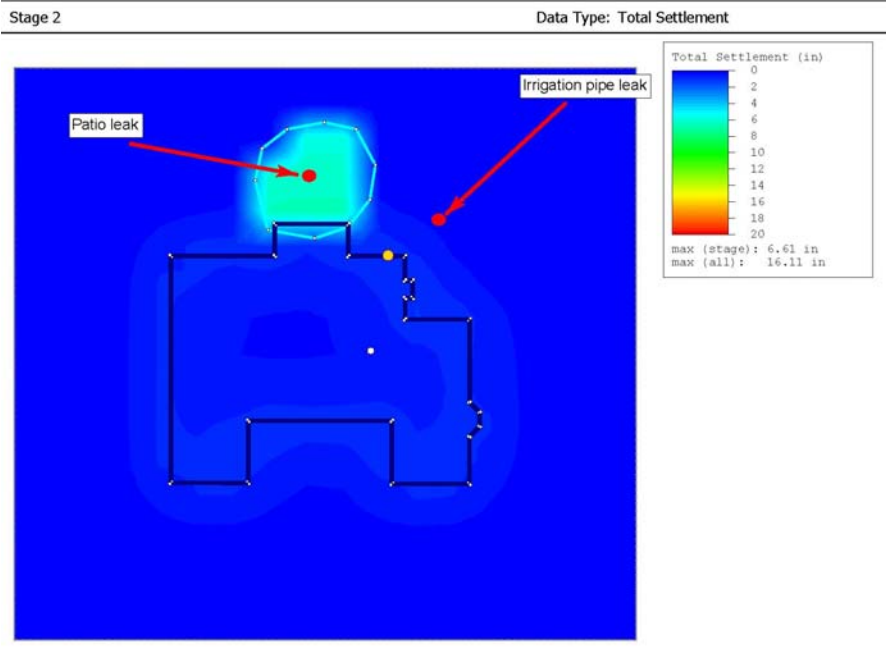


Figure 6b. Stage 2 - Settlement caused by both hydroconsolidation settlement and consolidation settlement, combined

Stage 3

Data Type: Total Settlement

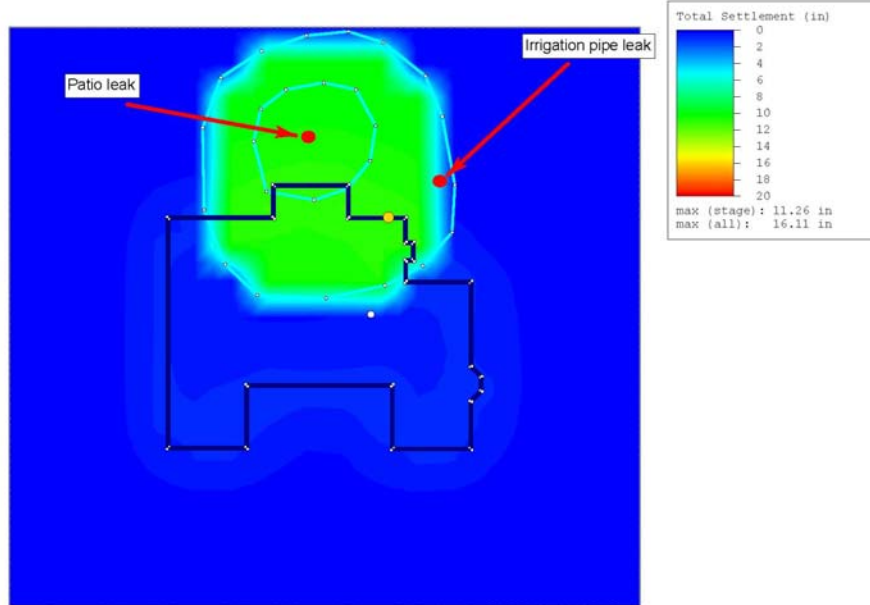


Figure 6c - Stage 3 - Settlement caused by both hydroconsolidation settlement and consolidation settlement, combined

Stage 4

Data Type: Total Settlement

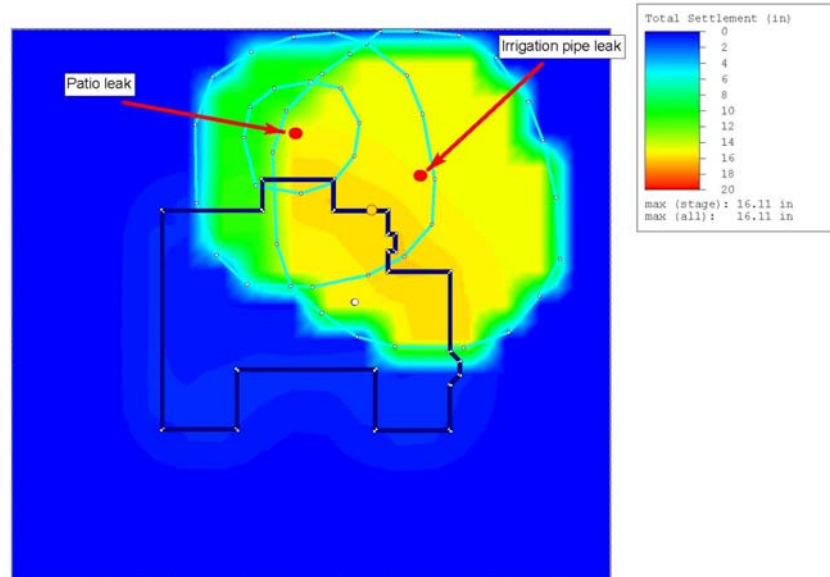


Figure 6d - Stage 4 - Settlement caused by both hydroconsolidation settlement and consolidation settlement, combined

Conclusion

When estimating collapse potential at a site that has experienced a significant, rapid influx of water from the surface, it is important to consider the potential for both hydroconsolidation-settlement and consolidation-settlement at the same time. Rocscience's *Settle^{3D}* program is ideally suited to performing those combined analyses as well as more conventional collapse-settlement analyses where hydroconsolidation is considered by itself.