

# MINE SUBSIDENCE EVENT AT WASHINGTON WEST APARTMENTS<sup>1</sup>

David B. Wilson<sup>2</sup>, Mitchell W. Weber,<sup>2</sup> John Purdy,<sup>2</sup> and Patricia Acker<sup>3</sup>

**Abstract:** A major mine subsidence event occurred in Scranton, PA in early 1993. The initial damage included breakage of gas and water lines, cracking of pavements and sidewalks, and architectural damage to the seven-story apartment building that houses about 150 elderly persons. Visible damage included a 3/4-in dilation of the expansion joint separating the building, approximately 200 interior and exterior cracks, and distress to utility lines. The Office of Surface Mining Reclamation and Enforcement (OSM) funded an integrated geotechnical and structural engineering investigation to determine the cause of the subsidence, the limits of affected areas, and the nature of damage to the building. Work included interior surveys, exterior surveys, installation of crack gages, eight subsurface borings, review of building design drawings, review of geologic and mining data, and structural analysis of the rigid steel frame building. The surveys showed the building had undergone movements consisting of a lateral translation, a longitudinal differential settlement, and a transverse differential settlement. Preliminary structural analyses showed that the differential settlements had introduced significant additional stresses in some of the building columns.

This paper provides a case history of the cause and effects of the subsidence event. The techniques used to collect and analyze the data are presented along with the findings of the geotechnical and structural engineering investigations. The paper also describes emergency actions that were implemented, the remedial alternatives that were considered, and the method selected as the recommended alternative.

## Background and History

### Description of Structure

The Washington West Apartment building is located on Washington Avenue in Scranton, PA. The building (fig. 1) is a seven-story apartment structure approximately 50 ft wide by 280 ft long. The structure was constructed in 1969 for the present owner, the Scranton Housing Authority, and provides housing for about 150 elderly citizens.

### Mining History

Active mining of eight anthracite coalbeds occurred between 1860 and 1937. Except for the top mine, named Big Vein, all of the coal veins were mined by room-and-pillar methods. Approximately 33% to 45% of the coal was left in place to serve as support pillars. All of the mines were either partly or fully flushed in the area of the apartment building prior to 1970.

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<sup>2</sup>David B. Wilson, Geotechnical Engineer, Mitchell W. Weber, Geologist, and John Purdy, Structural Engineer, Gannett Fleming, Inc., Harrisburg, PA.

<sup>3</sup>Patricia Acker, Chief of Branch of Anthracite, OSM, Wilkes-Barre, PA.

The Big Vein Mine is 70 to 90 ft below the ground surface with an average thickness of about 15 ft within the project area. Prior studies estimated that only 20% to 30% of the coal remains in this mine, and observed roof collapses occurred in the mine within the area of the northern end of the apartment building. At the time of the last study, 25 yr ago, roof falls were reported to extend 20 to 30 ft above the floor of the mine.

### **Foundation and Structural Design**

The apartment building foundation consists of a modified mat that was designed to span a 20-ft-wide zone of nonsupport in anticipation of a "pothole" type of subsidence failure below any individual interior column, and a 10-ft-wide span along the mat periphery.

The Washington West Apartment building is a seven-story rigid steel frame structure with a masonry facade. Structurally, the building is divided into two separate structures by an expansion joint. The expansion joint extends through the foundation. The only connection between the two sections of the structure is through the use of tie plates attached to the column webs on each side of the expansion joint.

All beam-to-column connections are designed to develop the full-moment capacity of the beam. Though this method of design avoids the use of cross bracing and lessens the weight of steel required, a rigid frame structure is susceptible to overstressing due to differential support settlement.

### **Movement History and Characterization**

The history of movements preceding the January 18, 1993, subsidence event is unknown except in general terms as reported by the Housing Authority's building maintenance personnel. Minor cracking was reportedly repaired in the concrete block walls on the ground floor and stairways prior to that date. On January 18, 1993, stress cracking was noticed by Housing Authority employees, and "creaking noises" were heard by residents. The Wilkes-Barre office of OSM received a subsidence complaint and responded by dispatching technical representatives to the site for an initial evaluation.

A walk-through visual survey of the building and grounds revealed several indications of lateral and vertical movements. Inspection personnel recorded 3/4-in lateral movement at the expansion joint. About 200 cracks were observed in the walls and floors of the public areas of the building, including hallways, stairwells, storage areas, the boiler room, the day room, and office spaces. Dilation of the cracks ranged from tight to several millimeters. Some of the previously repaired cracks had reopened. Vertical or torsional movement of the building was not determinable during the site visit. Exterior evidence of ground movements included observations of tension cracks in the pavement of Washington Avenue, lateral displacement of street curbs and sidewalks, and broken gas and water lines in the immediate vicinity of the apartment building. Fig. 2 shows a tension crack in the pavement of Washington Avenue along the front of the apartment building.

### **Emergency Actions Implemented Prior to Commencing Detailed Investigations.**

OSM implemented a number of actions in response to the subsidence event. The agency quickly responded to the initial complaint by the Scranton Housing Authority and, recognizing the potential gravity of the situation, simultaneously implemented an emergency abatement action and began the procedures to contract outside engineering services to assist with the project.

Concurrent with the Gannett Fleming investigation, OSM undertook an aggressive mine-void-filling program to immediately slow the progression of the subsidence. The OSM program targeted the uppermost coal seam, the Big Vein, with the grouting operation. Approximately 25 injection borings were drilled in the

immediate vicinity of the Washington West Apartment building. About 3,000 cu yd of concrete and grout were injected into mine voids.

### **Investigations and Findings**

An instrumentation program to monitor movement of the apartment building and surrounding ground surface was established by Gannett Fleming, Inc. The instrumentation program inside the apartment building consisted of establishing and monitoring settlement points on each floor and installing and monitoring crack gages at points of visible distress. Exterior instrumentation consisted of establishing and monitoring ground settlement points and surface lateral movement points. Instrumentation monitoring was performed on a weekly basis during April. An additional survey was completed in October 1993. Details of this instrumentation program and the findings are presented below.

#### **Interior Elevation Surveys**

The interior elevation surveys were established to provide data to evaluate measurable ongoing movement and to provide information for the structural analysis of the steel superstructure. Settlement points were established along the center line of the main hallway of the building on each floor. All surveys were performed using a digital electronic level that accurately measures elevations in a metric scale to four decimal places, i.e., 0.0001 m.

Typical movements along the hallway centerline are presented on fig. 3. This figure shows that most of the settlement typically occurs within the northernmost 60 ft of the building. The apparent total settlement is 3.36 in along the north-south axis of the building and 1.0 in along the transverse direction, with the northeastern corner of the building having settled more than the northwestern corner. A one-month downward movement of 0.1 in was recorded during April 1993. Additional downward movements of 0.36 in vertical and 0.3 in transverse occurred between April and October 1993.

#### **Crack Gage Monitoring**

A total of 64 crack gages were installed across cracks both inside and outside the building. The primary purpose of the crack gages was to provide a simple on-site method for housing authority personnel to determine if movements were continuing.

#### **Exterior Elevation Surveys**

Ninety vertical survey points were established outside the building. Fig. 4 is a plot of the measured settlement at each survey point indicates a trough pattern of subsidence in the area to the northeast of the apartment building. The maximum settlement of about 1.4 in occurred in the April to October 1993 monitoring period. This settlement pattern is in agreement with the observed tension cracks that have developed in this area and the deformed shape of the building, according to the interior survey and crack gage monitoring analysis.

#### **Structural Analyses**

A baseline structural analysis of the building was performed using the as-built condition of the northern half of the structure without any settlement loads. This analysis was done to provide the baseline member stresses for comparison to an additional analysis reflecting the condition of the deformed structure at the time of the inspection.

The building was analyzed using STAAD III computer software. The building was modeled as a three-dimensional rigid frame structure consisting of 25 supports, 235 joints, and 483 members. Dead, live, and wind loads were computed in accordance with the 1990 BOCA Code.

A second analysis incorporating the April 1993 surveyed column elevations was performed to determine the magnitude of stresses that had been induced in the structural framework as a result of the movements. It was found that stresses had increased significantly in some of the columns, and that several of the columns may be overstressed beyond normally permitted design values by more than 20%, which is considered unacceptable as a permanent condition. Additional movements that occurred between April and October 1993 have further increased the column stresses.

### Geologic Exploration

The geological exploration program consisted of eight HQ-size (nominal 4-in diameter) borings drilled around the periphery of the apartment building.

The subsurface strata can be characterized as four layers consisting of the soil and the three rock intervals. The soil layer exhibits adequate densities and does not appear to be contributing to the settlement of the apartment building. The character of the lowest rock interval, between the Top and Bottom Split of the New County, appears to be relatively stable and is not contributing to the surface subsidence. The rock interval between the Big Vein and the Top Split of the New County has significant subsidence potential in the areas along the northeast portion of the building. The very poor quality of the cap rock and the conditions in the Big Vein result in this interval having the highest potential for subsidence. Subsidence related to the Big Vein in the area beneath and north of the Washington West Apartment building is the principal cause of the distress affecting the structure, with a possible secondary contribution from subsidence related to the Top Split New County Vein.

### Description of Remedial Alternatives Considered

#### No Action

This alternative would involve taking no action except to continue to monitor the movement of the building. To be feasible, the monitoring program would be required to provide a warning that would be sufficiently early for remedial action to be taken. This is not considered to be an acceptable alternative because of the magnitude of the damage that has occurred, and because the geologic conditions indicate significant potential for additional subsidence. A warning provided by continuing the monitoring program probably would not provide sufficient time to accomplish repairs without encountering significant additional structural damage to the building.

#### Structural Strengthening of Building Frame

Column strengthening in most buildings is a major undertaking, and this building is no exception. The columns must be exposed to add strengthening steel to either reduce the unbraced length and/or increase the section properties. The preliminary structural analysis indicates that column strengthening might be required to remedy overstressing that has occurred. Column strengthening is not considered to be appropriate, however, as a general remedy to the subsidence problem because it does not address the fundamental cause of the movements.

### Column Leveling

In certain buildings the effects of subsidence may be counteracted by jacking the columns back to their original position. The column can be braced during jacking and then grouted under the base plate to hold it in place. This operation could be repeated if additional subsidence occurred. This type of column leveling is generally limited to structures with simple base-plate-to-foundation connections. The columns for this building have moment connections to the foundation. A jacking operation for this type of column becomes inordinately difficult, if not impossible, since high shear loads in two directions as well as rotation at the base of the column must be resisted while allowing vertical movement.

### Foundation Grade Restoration

This alternative involves leveling the foundation and columns by lifting the foundation. The restoration would be performed by lifting the foundation, using the stage down compaction grouting technique. The existing foundation of this apartment building is a mat foundation, which is typically considered a rigid foundation. In addition, it has been modified and made significantly more rigid to span up to 20 ft of nonsupport due to pothole subsidence. The load-distributing characteristics of this mat would be adverse for compaction grouting because the lifting forces would be spread out. In addition, there is a significant inconvenience to the residents and staff because all of this work is performed within the building.

### Mine Flushing

Mine flushing is a technique used to fill the mine void with fine or coarse aggregate materials. This procedure involves drilling holes from the ground surface into the mine from which the flushing materials and water can be pumped into the mine. Advantages of this method are a low requirement for quality control and utilization of nonspecialized equipment and readily available materials. However, because the material is placed in a very loose condition, there is consolidation of the flushed material after placement. For this project, the magnitude of expected consolidation would allow some additional mine related subsidence to occur. This procedure is not considered to be appropriate because small additional settlements could seriously affect the structure because of the distress that the building has already undergone.

### Consolidation Grouting of Mines and Cap Rock

The principal objective of this alternative is to address the fundamental cause of the problem, which is the subsidence of the bearing stratum because of mine roof failure. The consolidation grouting procedure attempts to fill the mine voids and cap rock fractures as completely as possible by low pressure grouting with concrete and/or cement-fly ash grout.

A consolidation grouting program would entail (1) developing a grouting pattern that would confine an area that includes the affected portion of the building and (2) performing secondary grouting to fill within the confined perimeter. All of the grouting would be performed from the ground surface and outside the building. Angle holes would be used for grouting under the structure. Because the Top Split of the New County is already suspect as a possible contributing factor to subsidence, grouting would be recommended for that vein as well.

### Column Grouting Within Mine

This alternative involves constructing a grout or concrete column within the mine to support the roof. Basically these columns would act in a role identical to that of the coal pillars. Injection holes are drilled in a predetermined pattern, and the mine void is filled with concrete at each location. If a coal pillar is

encountered in the initial drilling, it is backfilled with grout. The grout columns would typically be installed using large air rotary rigs from the ground surface.

There are two disadvantages to this alternative: the final product cannot be readily inspected to evaluate the completeness of the treatment, and it is questionable whether the cap rock, weakened by the past subsidence, could span from support to support without causing additional subsidence.

### **Foundation Underpinning**

This alternative, using pin piles as the most feasible method of underpinning, provides support to the foundation, but does not address the fundamental cause of the movement. A pin-pile foundation would consist of two or three piles at each structural column to transfer the building load to the rock strata below the Big Vein Mine. The pin piles would develop their capacity in the rock between the Big Vein and Top New County Mine.

The disadvantages to this alternative follow: Pin piles do not address the basic cause of the movement; therefore, the piles would be subjected to the forces associated with lateral movement of the ground caused by further subsidence. Pin piles are very weak in lateral support and probably would fail by shearing if subjected to lateral loads. The piles would all be installed from within the apartment building, disrupting the daily affairs of the building residents and staff.

### **Recommended Remedial Alternative**

No one alternative completely addresses all the issues that are considered necessary to remedy the present condition and to mitigate future distress to the structure. Instead, a combination of some of these alternatives taken in a phased approach provides the most reasonable solution. The recommended course of action is based on engineering judgment considering the following factors:

- Extent of current damage to the building.
- Value of the building.
- Assessment of the geological conditions.
- Apparent nature of the subsidence event.
- Construction details of the building.
- Technical feasibility and potential effectiveness of the remedial alternatives.
- Impact to the residents of the building during the remedial construction period.

The recommended remedial repairs consist of the following elements: consolidation grouting of the Top Split New County Vein, the Big Vein, and the cap rock; and implementation of a monitoring program to verify that stabilization of the structure has been achieved. A detailed structural reassessment after stabilization of the structure is complete may be performed to determine the need for structural modifications.

The objective of the consolidation grouting is to mitigate the source of the problem. By filling the mines as completely as possible with a material that is not subject to significant consolidation after placement and grouting of voids and fractures in the overburden rock, future subsidence activity is expected to be minimal. The grouting program consists of a series of vertical holes, used to create a perimeter barrier around the work area, and a series of variable angle holes oriented in a fan pattern to grout the rock strata beneath the structure. The angle holes are staggered to achieve the maximum grout penetration with the minimum number of injection holes. The selection of the type of material and mix ratios will be determined in the field, based on the conditions encountered in each injection hole.

## Discussion

Integrated engineering methods comprised of geotechnical investigations, monitoring surveys, and structural analyses were used at the Washington West Apartments to determine the cause, nature, and extent of the subsidence; the extent of damage to the building; the applicability of abatement alternatives; and the extent of abatement required. None of the engineering methods, if used alone, would provide reliable answers to all of the issues listed above. When used together as an integrated tool, each method provides part of the data necessary for a comprehensive evaluation. Data from each method complement and reinforce data obtained from the other methods. An integrated approach using these tools provides a clear image of the total problem and results in selection of the most appropriate abatement method as well as defining the minimum required limits of abatement.



Figure 1. Washington West Apartment building in Scranton, PA.

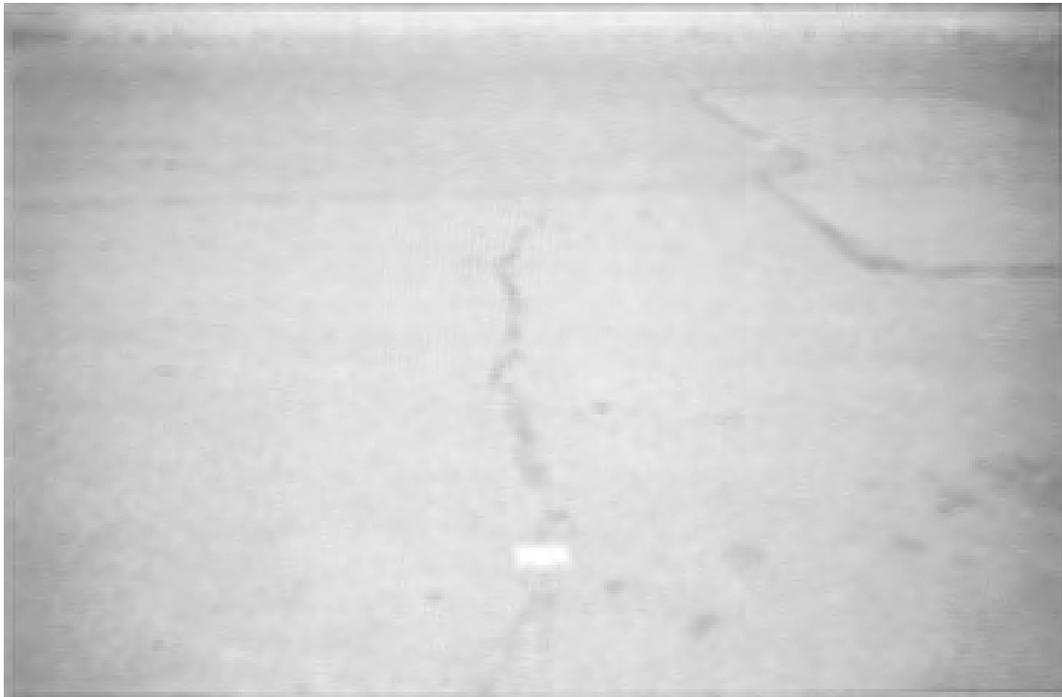


Figure 2. Typical tension crack in the pavement of the streets surrounding the Washington West Apartment building.

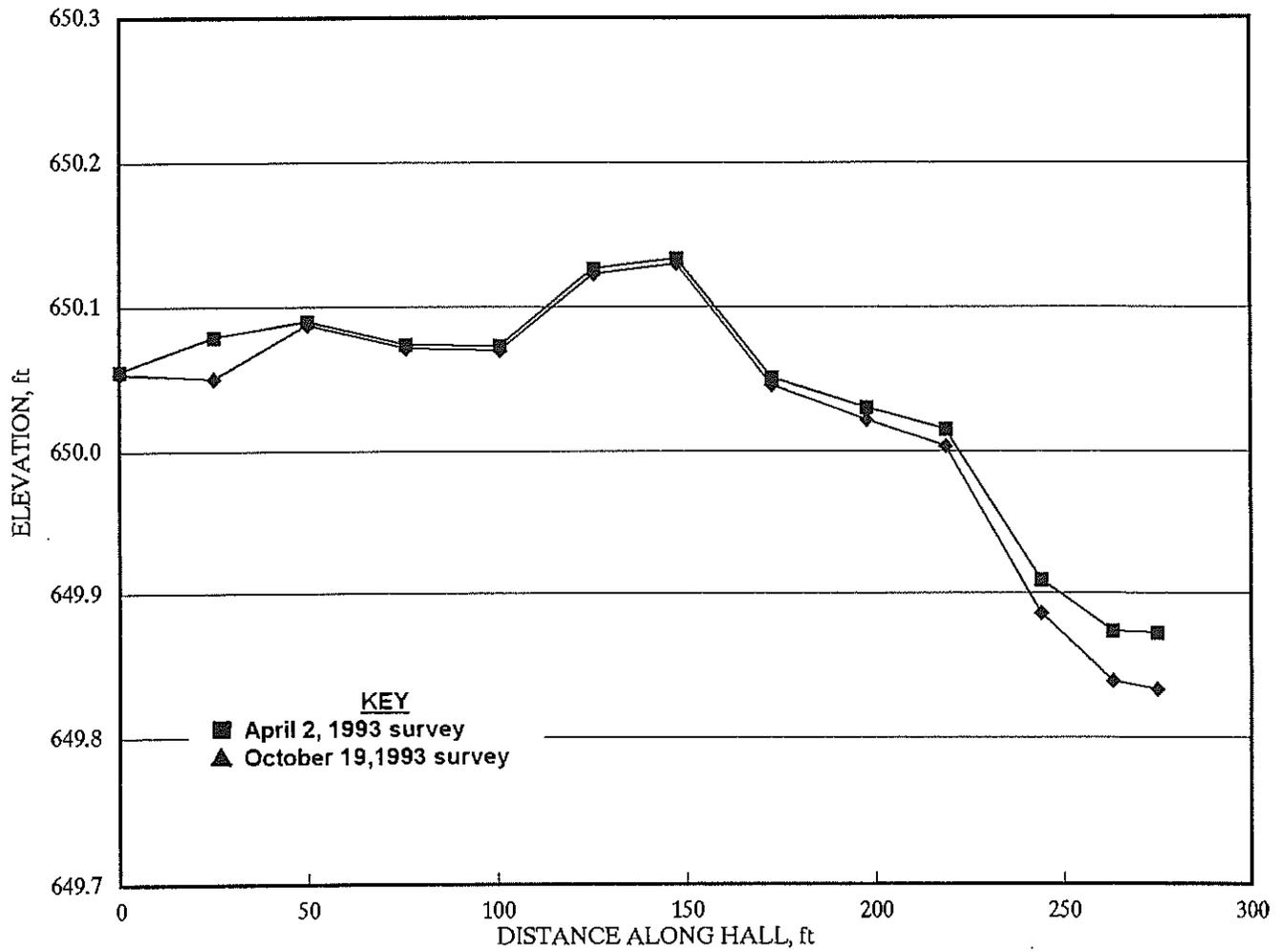


Figure 3. Plot of centerline profile showing typical vertical settlement in the northern portion of the apartment building.

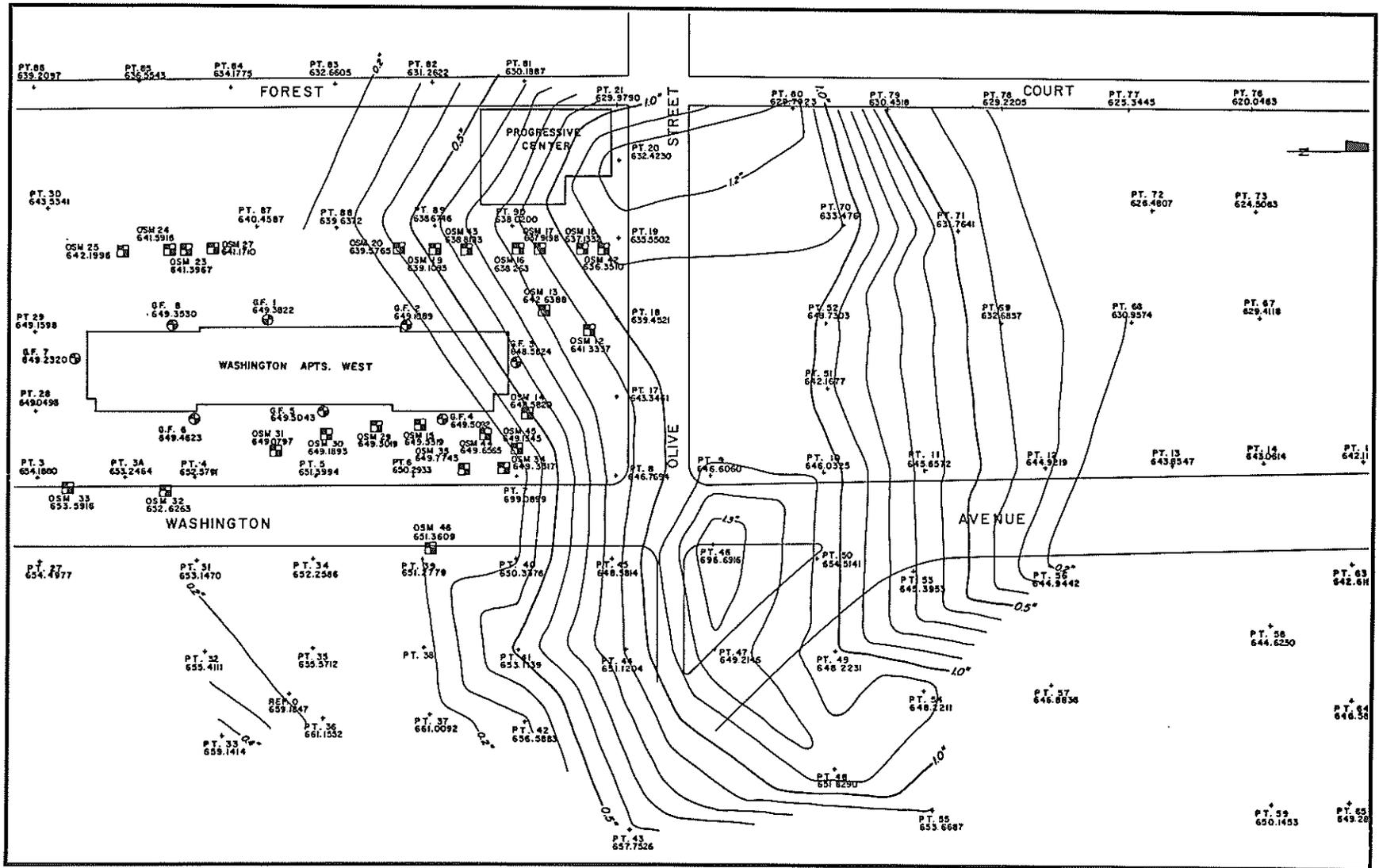


Figure 4. Settlement contour plan of the areas around the Washington West Apartments.