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REVIEW OF ALL SUBSIDENCE IN THE WEST UNITED STATES OF AMERICA

Morteza Nateqi[1*], Hamed Niroumand[2]

1*. Bachelor Student, Department of Civil Engineering, Buein Zahra Technical University, Qazvin, Iran, E-mail: nateqi.morteza@gmail.com

2. Post-Doc Assistant Professor, Department of Civil Engineering, Buein Zahra Tachnical University, Qazvin, Iran, E-mail: niromandh@gmail.com

Subsidence is a hazardous phenomenon that occurs like a gradual settling or sudden sinking of Earth's surface due to subsurface movements of underground materials. Subsidence is one of the biggest global problems. It has occurred for many times in the United States of America. It causes a lot of different damages. Sometimes, it is really difficult to make up the damages; But Sometimes It is not possible. So, subsidence and its implications are considered two important issues which must be known and studied before they accomplish. Considering the situation, subsidence can have different amounts of depth and width. A subsidence with big measurements indicates a bigger attention. This article is about all subsidence have occurred in the West United States of America. It is really necessary to study about different kinds of hazards and their effects on the world. In that case, the number of hazards will be decreased or they won't be accomplished anyway.

Keywords – Subsidence, the United States of America, damage, cause, measurement, California

Introduction

Sometimes the Earth's surface gets started to be settled or sunk owing to subsurface movement of underground materials. Subsidence is a hazardous phenomenon that can be occurred gradually or suddenly [National Research Council, 1991]. Subsurface layers of ground have a variety of displacement mechanisms. Among levels of this variety, the last one is termed "Land Subsidence" [Thomas L. Holzer, 1988]. Mostly due to human activities, the causes of subsidence are depressuring of underground reservoirs, extraction of petroleum riverine damming [Thomas L. Holzer, 1988], loss of freshwater inflow and extensive land use changes [Mohammad E. Al Mukaimi et al, 2018]. But it can also be caused by natural reasons, such as inundation or increased flooding (caused by loss of land elevation), withdrawal of fluids (groundwater, petroleum or geothermal) or resources [Thomas L. Holzer, 1988], anaerobic decomposition, wind erosion and shrinkage or dissolution of soil [Priyanka Sharma et al, 2016].

Groundwater in California is an important resource which provides water supplies for people of the state. It relatively impacts on economy, wildlife habitats and ecosystems. In California, ground water provides approximately 40% of the water which is needful in an average year. The main cause of land subsidence in California is related to decline of groundwater or its withdrawal (Table 1) [James W. Borchers et al, 2014].

The first area faced with land subsidence due to groundwater withdrawal, was the northern Santa Clara Valley in California. To support agricultural, industrial and domestic uses, big amount of groundwater was withdrawn and resulted in a great land subsidence over a wide area [James W. Borchers et al, 2014].

The San Joaquin Valley in California became one of the most productive agricultural areas in the world, just because of mining groundwater for agriculture. Nowadays, California is considered the largest agricultural-producing state in United States of America; because it produces 11 percent of the total agricultural value. The San Joaquin Valley, The Sacramento Valley and the Sacramento-San Joaquin delta are the main areas in the Central Valley of California. This region produces 25 percent of the total table food on only 1 percent of the country's farmland. The Development of agriculture and availability of water supplies for domestic uses or even irrigation are completely linked to the history of land subsidence in the San Joaquin Valley [U.S. Geological Survey Circular 1182, 1999].

The location of maximum subsidence is in the San Joaquin Valley Southwest of Mendota, California. To know the measurement of land subsidence in this area, Dr. Joseph F. Poland attempted to find it. Altitude of land surface was determined by him in different years [1925, 1955 and 1977] and marked by signs on a pole (fig. 1) [USGS, 2016].

In table 1, there are names and necessary information of all subsidence which have occurred during a particular time. It is important to know about the names and features of hazards. In other words, there is a strong need for coordination of monitoring and collecting data. In this way, it would be clear how to control a subsidence very well or prevent it from exceeding.

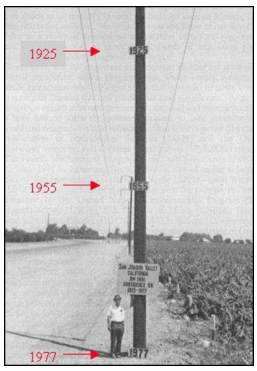

Fig. 1. Dr. Joseph F. Poland- Land subsidence in San Joaquin Valley between 1925 and 1977

In table below, subsidence all over the California and some of their important features have been introduced; such as occurrence time, subsidence measurement (depth and width), their causes and damages.

Table 1

Subsidence in California and details

Location		Period	Measurement	Reason(s)	Damage(s)	Scholar/Author
Santa Clara valley	Valley	1912	3ft.	Irrigation of valley	Earth fissure, damage of water wells or buildings	Fowler, 1981
		1934-67	2-8 ft.	decline of artesian pressures		U.S. Geological Survey Circular 1182
San Jose	Downtown	1910-95	14 ft. 100 mi2	Massive ground-water withdrawal		U.S. Geological Survey Circular 1182
San Joaquin valley	Half of the valley	1970	1 ft. 5200 mi^2	water withdrawal	Impact on structure and construction of canals	Poland et al., 1975
	Southwest of Mendota	1925-75	28 ft.			Ireland and others, 1984
Antelope valley	valley	1930-92	6.6 ft.	Gradual compaction of susceptible aquifer systems	Loss of aquifer storage, Increase of flooding, cracks and fissures, damage to structures	Ikehara and Phillips, 1994
Coachella valley	Near Palm Desert	1995-2010	1.35 ft.	Groundwater pumping	Ground levels to decline at different rates, damage to infrastructure such as roads, bridges, and canals	Sneed and others, 2001; 2002; Sneed and Brandt, 2007
	Indian Wells	1996-2010	0.85 ft.			
	La Quinta	1996-2000	1.5 ft.			
San Bernardino (Mojave desert)	El Mirage lake	Apr 21, 1995-May 1, 1999	0.16 ft.	Declining water levels in fine grained (clay and silt) sediments Unmonitored development of groundwater in desert basins areas	Fissures Surface drainage routes Damage surface and subsurface infrastructure	Sneed et al., 2001
	Harper lake	1992-2009	0.28 ft.			
	Troy lake	1993-99	0.15 ft.			
		2004-09	0.225			
	Coyote lake	2004-09	0.2 ft.			
	Lucerne lake	1992-99	0.33 ft.			
		1999-2000	0.64 ft.			
	Bicycle Lake Playa	1993-2006	0.88 ft.	Decline of ground-water levels	The fissure opens at a rate of 0.005 ft/yr	The USGS, in cooperation with the Fort Irwin National Training Center (NTC)
	Chino	1986-93	3.9 ft.	Decline of water levels	Deformation (depth: 1,400 ft. and width: 600 ft.)	Stewart and others, 1998
		1987-95	2.3 ft.			Wildermuth Environmental, 2007
San Jacinto valley	Eastern Riverside county	For the past 10000 to 40000 years	450 ft.	Tectonic deformation, aquifer compaction, groundwater withdrawal, down-warping of the valley	Linear fissures and sinkholes Arcuate fissuring	Morton, 1977
	East of the trough-bounding Casa Loma fault	1939-59	2.34 ft.			Proctor, 1962 and Morton, 1977
	The valley	1970-74	0.075 ft.			Lofgren, 1976 and Morton, 1977
Sacramento valley	Between Zamora and Knights	1935-64	2 ft.	Pumping for irrigation and public water supplies during	Damage to concrete pads at irrigation wells	Lofgren and Ireland, 1973

	Landing in northern Yolo County			droughts	Increased extent of flooding	Blodgett et al., 1990
Sacramento valley	Near Arbuckle in southern Colusa County	1935-64	1 ft.	Pumping for irrigation and public water supplies during droughts	Damage to concrete pads at irrigation wells Increased extent of flooding	Lofgren and Ireland, 1973 Blodgett et al., 1990
	Central Yolo County between Zamora and Davis	1935-64	1.5 ft.			
	Between Dixon and Zamora	1935-64	4.1 ft.			
	Between Knights Landing and Stockton	1949	3.17 ft.			
	North of Woodland	1988-92	0.9 ft.			Ikehara, 1995
San Luis Obispo County	Northeast of Paso Robles	March 28-August 15, 1997	0.067 ft.	Concentrated pumping	Reliable wells have gone dry	Valentine et al., 2001
	Atascadero area	March 28-August 15, 1997	0.09 ft.	seasonal water-level declines	Reliable wells have gone dry	Valentine et al., 2001
	The city (Inland from the central California coast at Morro Bay)	1991	1 ft.	Water shortages Drought	Wells began to notice unusual effects The Bear Valley Shopping Center experienced differential subsidence	John Rosesetti, Los Osos Valley Associates, oral commun., November 4, 2013
Cambria	The central California coast	1976-77	-	Substantial decline of groundwater levels	Earth fissures	Cleveland, 1980
Mojave River basin	The Fremont Valley	1962-78	2 ft.	Groundwater withdrawal	Floods during winter rains	Pampeyan and others, 1988
	The Lucerne Valley (East of Victorville)	1969-75	2 ft.	Decline of groundwater levels	-	Sneed et al., 2003
	Lucerne Lake	Apr 24, 1992- Nov 8, 1999	0.3 ft.		Polygonal cracks, earth fissures (3 ft) in width and depth	
	Eastern shores of the Harper Dry Lake playa near Lockhart	1992-99	0.28 ft.	Decline of groundwater levels Inelastic compaction	persistent pattern of deformation	Stamos et al., 2001
Los Angeles	The 40-km long Santa Ana Basin	Apr 1998–May 1999	0.1 ft.	Oil-field operations Groundwater extraction and injection	Seasonal deformation fissures	Bawden et al., 2001
		May–Sep 1999	0.2 ft.			

Santa Barbara	Cuyama Valley	Dec 2002-May 22, 2008	0.18 ft.	Inelastic compaction of the aquifer system	The valley and surrounding mountains are moving upward	Everett et al., 2013
San Gabriel	The valley	May 1998 - May 2000	0.08 ft.	Decrease in the water level	-	King et al., 2007 and Argus et al., 2005
Pomona	Pomona area	1992-2013	4.2 ft.	Decline of groundwater levels	Ground fissuring	Land Subsidence Committee 2013 Annual Report
Oxnard	Oxnard plain	1939-78	2.6 ft.	Over-pumping of ground water	-	Earrthcache masters

Conclusions

Subsidence is an unrecognized problem in California. Recently Sneed at el. (2013) have become successful in raising awareness of ongoing land subsidence within the geotechnical community. But it is important to educate the general public on importance and influences of land subsidence. Actually, the implications of land subsidence can make it more and more important (James W. Borchers et al, 2014).

According to the table above, it is clear that the main reason of land subsidence in California is mostly related to groundwater. In spite of the fact that most of these dangerous hazards have caused by groundwater withdrawals, they vary in some factors; such as time period. Some of them have occurred gradually but otherwise, some of them have not.

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