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Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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PILE FOUNDATIONS WITH ELEVATED PILE CAPS FOR SEISMIC ZONES

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Abstract. *Relevance.* Seismic isolation of buildings remains a highly critical issue in earthquake engineering. In this context, experimental research has demonstrated that pile foundations with a high pile cap exhibit a significant seismic isolation effect compared to low pile caps, which have shown only limited seismic isolating efficiency based on the aftermath of strong earthquakes. *Objective.* To obtain data on the dynamic and dissipative characteristics of full-scale pile foundations featuring both hinged and rigid pile-to-cap connections with a high pile cap under seismic-type loading based on comprehensive experimental studies, and to justify their implementation in engineering design practices. *Methods.* The field experiments included static testing of single piles, as well as static, dynamic, and seismic-blast testing of full-scale pile foundations with a high pile cap. Two types of connections between the pile heads and the cap were evaluated: a hinged connection (R-2) and a rigid connection (R-1). Specialized testing equipment and measuring instruments were utilized to record displacements and accelerations. *Results.* Single pile testing, serving as analogs for the capped piles, established that the effective embedment depth of the piles in the soil is 33–59 cm (equivalent to 1–2 times the lateral dimension of the pile cross-section) and determined their dissipative characteristics. For the pile caps, ultimate horizontal displacements, dynamic responses, oscillation periods, and logarithmic decrements were determined. The oscillation decrement of the hinged cap (R-2) exceeded that of the rigid cap (R-1) by 1.6 times, while its displacement was 4 times greater. The results of the seismic-blast loads demonstrated good correlation with the dynamic test data for the R-2 cap and satisfactory correlation for the R-1 cap. *Conclusions.* The implementation of pile foundations with a hinged connection between the pile heads and a high pile cap can significantly reduce seismic loads on buildings by 2 to 4 times, depending on soil conditions and seismic demand characteristics. It is recommended to deploy this type of pile foundation in combination with various types of dampers to ensure efficient and reliable seismic isolation for buildings.

Keywords: seismic isolation, pile foundations, static and dynamic testing

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СЕЙСМИКАЛЫҚ АЙМАҚТАРҒА АРНАЛҒАН БИІК РОСТВЕРКТІ ҚАДА ІРГЕТАСТАРЫ

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Аннотация. *Өзектілігі.* Сейсмотұрақты құрылыста ғимараттарды сейсмикалық оқшаулау өте өзекті мәселе болып қала береді. Осы тұрғыда, жүргізілген эксперименттік зерттеулердің нәтижелері бойынша жоғары ростверкті қадалы іргетастар, күшті жер сілкіністерінің салдары бойынша белгілі бір сейсмооқшаулағыш тиімділік көрсеткен төмен ростверктермен салыстырғанда, айтарлықтай жоғары сейсмооқшаулағыш әсерге ие екендігін дәлелдеді. *Мақсаты.* Кешенді эксперименттік зерттеулер негізінде сейсмикалық үлгідегі жүктемелердің әсерінен жоғары ростверкпен шарнирлі және қатаң қосылған қадалы іргетастардың динамикалық және диссипативтік сипаттамалары бойынша нәтижелер алу. Олардың жобалау тәжірибесінде қолданылуын негіздеу. *Әдістері.* Тәжірибелер далалық жағдайларда табиғи өлшемдегі жеке қадаларды статикалық сынауды, сондай-ақ жоғары ростверкті қадалы іргетастарды статикалық, динамикалық және сейсмикалық-жарылыстық сынауды қамтыды. Мұнда қада бастарының ростверкпен байланысының екі түрі зерттелді: шарнирлі (Р-2) және қатаң (Р-1). Орын ауыстырулар мен үдеулерді тіркеу үшін арнайы сынақ жабдықтары мен өлшеуіш құралдар пайдаланылды. *Нәтижелері.* Ростверк қадаларының аналогы ретінде жеке қадаларды сынау нәтижесінде қадалардың топырақтағы шартты қысылу тереңдігі 33–59 см-ге немесе қада қимасының көлденең өлшемінің 1–2 еселігіне тең екендігі анықталды және олардың диссипативтік сипаттамалары алынды. Ростверктер бойынша шекті көлденең орын ауыстырулар, динамикалық реакциялар, тербеліс кезеңдері мен декременттері анықталды. Р-2 шарнирлі ростверктің тербеліс декременті Р-1 қатаң ростверкінен 1.6 есе, ал орын ауыстыру көрсеткіші 4 есе артты. Сейсмикалық-жарылыстық әсерлердің нәтижелері Р-2 ростверкі үшін динамикалық сынақтардың деректерімен жақсы, ал Р-1 үшін қанағаттанарлық сәйкестік көрсетті. *Қорытынды.* Құрылыста қада бастары жоғары ростверкпен шарнирлі қосылған қадалы іргетастарды қолдану топырақ жағдайлары мен сейсмикалық әсерлердің сипаттамаларына байланысты ғимараттарға түсетін сейсмикалық жүктемені 2-ден 4 есеге дейін айтарлықтай төмендетуге мүмкіндік береді. Ғимараттарды тиімді және сенімді сейсмооқшаулауды қамтамасыз ету үшін қадалы іргетастардың бұл түрін демпферлердің әртүрлі түрлерімен кешенді түрде қолдану ұсынылады.

Түйін сөздер: сейсмооқшаулау, қада іргетастары, статикалық және динамикалық сынақтар

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СВАЙНЫЕ ФУНДАМЕНТЫ С ВЫСОКИМ РОСТВЕРКОМ ДЛЯ СЕЙСМИЧЕСКИХ ЗОН

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Аннотация. *Актуальность.* В сейсмостойком строительстве одной из наиболее актуальных проблем остается сейсмоизоляция зданий и сооружений. В этой связи свайные фундаменты с высоким ростверком представляют значительный научный и практический интерес. По результатам экспериментальных исследований они продемонстрировали выраженный сейсмоизолирующий эффект по сравнению с фундаментами с низким ростверком, которые, согласно анализу последствий сильных землетрясений, также проявляли определенные сейсмоизолирующие свойства. *Цель.* На основе комплексных экспериментальных исследований получить данные о динамических и диссипативных характеристиках свайных фундаментов с высоким ростверком при шарнирном и жестком соединении оголовков свай с ростверком под действием нагрузок сейсмического типа, а также обосновать возможность их применения в практике проектирования. *Методы.* Испытания включали статические исследования одиночных свай, а также статические, динамические и сейсмовзрывные испытания свайных фундаментов с высоким ростверком в натуральную величину в полевых условиях. Рассматривались два вида соединения оголовков свай с ростверком: шарнирное (Р-2) и жесткое (Р-1). Для регистрации перемещений, ускорений и других параметров использовались измерительные приборы и специальное испытательное оборудование. *Результаты*. По результатам испытаний одиночных свай, рассматриваемых как аналоги свай ростверков, определена глубина условного защемления свай в грунте, равная 33–59 см, или 1–2 боковым размерам сечения свай, а также установлены их диссипативные характеристики. Для ростверков определены предельные горизонтальные перемещения, динамические реакции, периоды и декременты колебаний. Декремент колебаний ростверка Р-2 превысил аналогичный показатель ростверка Р-1 в 1,6 раза, а перемещение - в 4 раза. Результаты сейсмовзрывных воздействий показали хорошую сходимость с данными динамических испытаний для ростверка Р-2 и удовлетворительную сходимость для ростверка Р-1. *Выводы*. Применение свайных фундаментов с высоким ростверком и шарнирным соединением оголовков свай в строительстве позволяет снизить сейсмическую нагрузку на здания в 2–4 раза в зависимости от грунтовых условий и характеристик сейсмических воздействий. Рекомендуется использовать данный тип свайных фундаментов совместно с различными видами демпферов для обеспечения более эффективной и надежной сейсмоизоляции зданий.

Ключевые слова: сейсмоизоляция, свайные фундаменты, статические и динамические испытания

Introduction. In the field of earthquake engineering, ensuring the reliable seismic resistance of buildings and structures remains a critical challenge. A specialized approach to this problem involves the seismic isolation of above-ground structures at the foundation level. Despite numerous patents and extensive experimental and theoretical research, only two or three types of seismic isolation foundations have seen widespread practical application–primarily lead-rubber bearings. More recently, steel spring isolators have been proposed, with their effectiveness experimentally validated, alongside traditional low-pile-cap foundations in weak soil conditions. The primary drawbacks of rubber-metal bearings are their high cost and the requirement for specialized types of rubber and steel, as well as the necessity for replacement at the end of their service life, which limits their mass application.

Evidence from high-magnitude earthquakes has shown that low-pile-cap foundations in weak soils provide a noticeable seismic isolation effect compared to conventional foundation types. However, as demonstrated by the results of these pioneering comprehensive experimental studies (and subsequently supported by similar research), high-pile-cap foundations exhibit superior seismic isolation characteristics compared to low-pile-cap systems. This significantly reduces seismic loads on the load-bearing structures of buildings and facilities. Furthermore, high-pile-cap foundations featuring a hinged connection between the pile heads and the cap have demonstrated a substantial seismic isolation effect.

Literary review. Major earthquakes, specifically the 7.9-magnitude Mexico City earthquake of June 28, 1957, provided the first evidence of the superior performance of pile foundations. According to an analysis by (Emilio Rosenblueth, 1957), buildings supported by pile foundations remained undamaged, while structures on other foundation types sustained varying degrees of damage.

According to research by Ushakov, 2011, pile foundations featuring an intermediate "cushion" made of inert materials have proven to be the most rational engineering solution for reducing seismic impacts on above-ground structures. This approach was developed by both international (Chile) and Soviet (Russia, Moldova) specialists. The defining characteristic of such foundations is the absence of a rigid connection between the pile cap and the piles. In this system, a sand-and-gravel cushion is spread and compacted over the heads of piles driven into Category III soils (based on seismic properties); a reinforced concrete structure, similar to a conventional pile cap, is then placed atop this cushion. In pile foundations with an intermediate cushion, the transmission of horizontal (seismic) loads to the superstructure is drastically reduced, as the energy is distributed and dissipated throughout the cushion.

Consequently, the behavior of buildings on low-pile-cap foundations significantly mitigates seismic loads on superstructures to a certain degree. This is due to the horizontal flexibility (compliance) of the pile foundations and the resulting energy dissipation within the soft soil strata during seismic events.

In line with this, a series of experimental and theoretical studies have been conducted to investigate pile behavior under seismic-type loading.

Researchers (Xiu Luo et al., 2001) proposed a method for evaluating the seismic resistance of existing pile foundations by analyzing response to seismic oscillations. This method was developed based on lessons learned from the devastating Hyogoken-Nanbu earthquake of January 17, 1995. A comparative analysis between the proposed evaluation method and the post-earthquake inspection results of affected pile foundations demonstrated strong correlation (good convergence).

In a paper by (Murono et al., 2000) the characteristics of forces acting on piles during earthquakes are examined in terms of inertial and kinematic forces. Most seismic design codes account for pile foundations based solely on inertial forces. However, soil deformation caused by seismic waves induces pile bending, leading to bending moments along the entire length of the pile. In their work, the dynamic response of a pile foundation subjected to lateral oscillations was investigated using a numerical "soil-pile-structure" interaction model with varying ratios of the structure's natural period (Ts) to the soil foundation's period (Tg). Based on linear and non-linear seismic analysis, they proposed a practical method for estimating the forces acting on a pile, accounting for both inertial response and the kinematic effect.

Furthermore, Kong et al., 2019 investigated the soil-pile-structure interaction of various pile caps under seismic impacts from the El Centro earthquake. A numerical model was developed for inclined pile groups within a "pile-soil-structure" system featuring both low and high pile caps. The results indicated that the vertical and horizontal displacements of both inclined and vertical piles with a high cap were significantly greater than those with a low cap. This increased displacement is a positive factor in mitigating seismic loads on buildings.

Kaustav et al., 2019 conducted a dynamic analysis of piles subjected to both vertical and horizontal loading under seismic conditions. It was observed that the free-field soil surface displacement initially increases, reaching a peak at a certain point during the oscillations, and subsequently remains constant over time due to localized failure of the liquefied soil surrounding the pile foundation. To derive P-Delta curves under dynamic loading conditions, various combinations of vertical and lateral loads were applied to the pile head to determine the peak bending moment acting on the pile.

Matsumoto et al., 1965 conducted static cyclic lateral load tests on large-scale pile foundations to investigate the influence of vertical loads and pile spacing ratios during earthquakes. The experiments utilized reinforced concrete raft foundations supported by 16 piles. The results demonstrated that a significant portion of the lateral force is transmitted through raft friction under high contact pressure, and that the piles experience tensile forces from the raft, acting as anchors during large displacements.

Thus, low-pile-cap foundations or reinforced concrete rafts that integrate pile heads and bear directly on the ground surface without a gap have shown a substantial seismic isolation effect during strong earthquakes.

Starting in 1974, pioneering comprehensive field experiments were conducted on full-scale high-pile-cap foundations featuring a novel hinged connection between the pile heads and the cap, compared against rigid connections. These were evaluated as effective seismic isolation systems under static, dynamic (seismic-type), and seismic-blast loading.

In the first stage, single pile tests were performed (Aubakirov et al., 1976) to establish a baseline for pile performance within groups. These tests determined bearing capacity and the logarithmic decrement of damping, derived from hysteresis deformation diagrams. In the second stage (Abakanov et al., 1977), static and dynamic parameters were obtained for two types of high-pile-cap foundations (hinged and rigid), followed by analytical modeling. The structural analysis was based on the fundamental methodologies of K.S. Zavriev and A.T. Aubakirov, which showed high correlation with the experimental deformation diagrams of the pile caps.

Subsequently, (Gaipov, 2014) optimized a specific seismic isolation system known as "pile-in-pipe." Structurally, this system is a variation of the high-pile-cap foundation. It was shown that under conditions of seismic uncertainty, this system functions as an adaptive (self-tuning) system, capable of adjusting its dynamic characteristics in response to seismic impacts of varying intensity. This makes it an optimal seismic protection system for minimizing horizontal accelerations.

(Belash et al., 2013) investigated construction principles for permafrost regions with high seismic activity using high pile caps. Their approach involves installing specialized dry friction dampers between the piles. Various design solutions for these damping devices were presented alongside an analysis of building behavior using this seismic protection system.

(Ajzenberg et al., 2012), in their research on the elasto-plastic performance of reinforced concrete piles within the "pile-in-pipe" system, confirmed that such systems belong to the class of adaptive seismic protection, capable of self-tuning their dynamic properties during earthquakes. They provided examples of practical implementation in existing structures.

In further publications, (Ajzenberg et al., 2012) identified the most effective configurations for the "pile-in-pipe" system based on site-specific geological and seismic conditions. A key advantage identified was the reduction of seismic loads when pile tips are embedded in deeper, more stable soil layers. This load reduction occurs due to two factors: the contrast between the weak upper soil layers and the dense lower bearing strata, and the decrease in ground oscillation accelerations as the depth of the outer pipe increases from the surface.

Finally, (Bakulina, 2016) conducted experimental model studies on the stability and deformability of horizontally loaded piles for structures such as power lines, power plants, and bridges. This work analyzed the impact of the superstructure on horizontally loaded piles, comparing stress and deformation levels under seismic, wind, and transport-induced loads.

Materials and methods. The comprehensive experimental program included static load tests of single piles, as well as static, dynamic, and seismic-blast testing of high-pile-cap foundations. Two distinct types of pile-to-cap connections were evaluated: hinged and rigid.

The field tests were conducted at a site characterized by a soil profile (within the pile driving depth) consisting of macroporous loams, ranging from stiff to hard consistency, with intermittent layers and lenses of varying grain-size sands. During the testing period for both single piles and pile groups, the groundwater table was located at a depth of 9 meters below the surface. Due to the high density and hardness of the soil, the piles were driven using pre-drilled pilot holes (lead holes).

Single Piles. The characteristics of the full-scale test piles, their driving depth, the magnitudes of the applied horizontal forces, and the points of horizontal displacement measurement (taken at the ground level and at the pile head using deflectometers) are summarized in Table 1.

Table 1. Key Characteristics of Single Piles.

Test Pile №.	Total Length, L *(m)*	Driving Depth, *l, m*	Concrete Grade	Reinforcement	Point of Horizontal Load Application *Ph*, l_0, *m*	Distance from Ground Level to Deflectometers, l_n, *m*	
						П-1	П-2
4	12.84	11.1	300	8Ø28 AIII	1.74	0.05	1.94

5	10.70	9.1	300	8Ø22 AIII	1.60	0.05	1.45
6	9.55	8.0	300	4Ø18 AIII	1.65	0.12	1.55

High-Pile-Cap Foundations. The characteristics of the full-scale experimental sections of pile foundations—featuring both rigid (P-1) and hinged (P-2) connections between the pile heads and the high pile cap—are summarized in Table 2.

Two types of pile foundations were tested, the first one - with a free-standing pile height of 1.6m. with rigid fixity of the pile heads into the cap, the second one - with a height of 2.1m. and a hinged connection of the pile heads with the cap, under a vertical load on each pile cap of 1200 kN. The primary characteristics of the pile caps are given in table 2.

Table 2. Key characteristics of pile caps.

Pile cap №	P-1				P-2			
Pile mark	SA-12ᶜ/10				SP-12ᶜ/10			
Concrete grade	300				300			
Pile № in the cap	1	2	3	4	1	2	3	4
Pile driving depth, m	9.8	9.7	11.1	10.8	11.1	11.1	4.8	11.0
Pile reinforcement	8 Ø 22 AIII				8 Ø 28 AIII			
Pile height above ground level, m	1.6				2.1			

Single pile tests were conducted by applying short-term static, alternating, incrementally increasing horizontal forces of the seismic type to obtain hysteresis deformation diagrams and dissipative parameters.

Pile cap tests were conducted under short-term static alternating incrementally increasing horizontal forces, as well as dynamic and seismic-blast impacts to obtain hysteresis deformation diagrams, dynamic, and dissipative parameters of the caps. The names of the measuring instruments and testing equipment used during static, dynamic, and seismic-blast testing are shown below. Measuring instruments for static tests: deflectometers, strain-gauge inclinometers; for dynamic and seismic-blast impacts: Geiger vibrograph, VBP-large displacement vibrograph, SPED-accelerometer; equipment for static and dynamic tests: hydraulic jack with pump station, load cell, quick-release load shaper for creating dynamic load.

Results and discussions. Based on the tests of single piles, the following results were obtained. Figure 1 shows the test setup and the envelope diagrams "P_h-y_h" and the calculated hysteresis diagram with varying pile stiffness coefficients as the load and displacement increase.

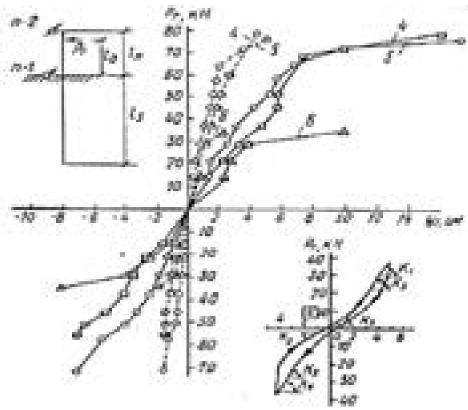

Figure 1. Single pile testing scheme, pile head and pile tip displacement diagrams "P_h-y_h", calculated hysteresis diagram and scheme.

Table 3 presents the main experimental results, pile head displacements and residual pile displacements at the ground level, bearing capacity, and the logarithmic decrement of damping determined from the hysteresis deformation diagrams according to the methodology.

It is evident from the table that with a decrease in the bearing capacity and stiffness of the piles, associated with the combination of the reinforcement ratio and the manifestation of soil dry friction forces along the lateral surfaces of the piles, an increase in the logarithmic decrement occurs (δ = 0.57, 0.61, 0.75) due to improved dissipative characteristics. Based on the pile stiffness at each loading stage, the effective fixity depth of the equivalent cantilever was determined, which equaled 1.1d (d - pile cross-section size, 0.3m) at small pile head displacements up to 15 mm, and 2.0-2.3d at large displacements up to 70 mm.

Table 3. Single pile test results.

Pile №	Loading cycles №	P_h, kN	S_h, cm	S_{res}, cm	δ
4	1	14.5	1.66	0.3	0.48
	2	21.3	2.76	0.24	0.65
	3	28.1	3.60	0.42	0.55
	4	35.7	4.16	0.33	0.55
	5	45.0	5.44	0.78	0.6
	6	50	6.82	0.98	0.58
Mean value					**0.57**
5	1	14.5	1.25	0.2	0.48
	2	20.6	1.4	0.2	0.84
	3	28.6	2.6	0.23	0.5
	4	35.6	3.35	0.45	0.52
	5	45.0	4.35	0.35	0.59
	6	50.0	5.8	0.75	0.5
	7	57.7	6.35	0.78	0.63
	8	65.0	7.65	1.0	0.82

Mean value					**0.61**
6	1	14.4	1.4	0.38	0.75
	2	20.6	3.08	0.36	0.58
	3	29.1	4.4	0.83	0.91
Mean value					**0.75**

Table 3 symbols: P_h kN applied horizontal force, S_h cm horizontal pile head displacement (P-2 table 1), S_{res}, cm residual displacements at ground level, δ damping decrement.

Static tests of pile caps. The following results were obtained from the pile cap tests. Figure 2 shows the envelope "load-displacement P_g-y_g" diagrams for pile caps P-1 and P-2, plotted based on the maximum loads and displacements at each stage.

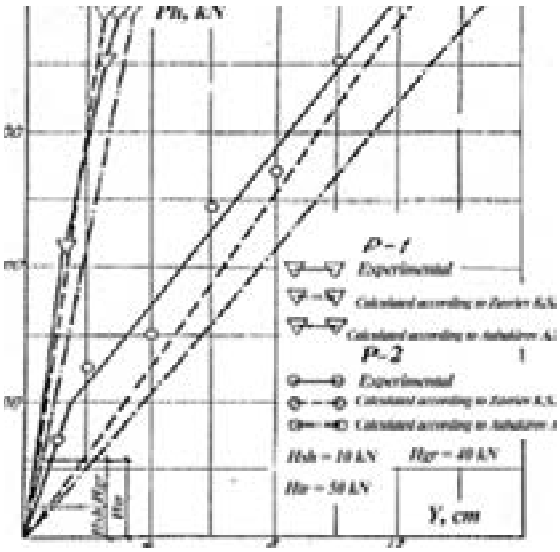

Figure 2. "Load-displacement P_h-y_h" diagrams for pile caps P-1 and P-2, plotted based on maximum step-by-step loads and displacements.

The applied ultimate horizontal loads were 386 kN for P-1 and 400 kN for P-2, with corresponding displacements of 3.0 cm for P-1 and 12 cm for P-2.

A break in the P-2 diagram, indicating a decrease in stiffness, occurred after overcoming (up to the point of sliding) the total dry friction forces in the hinged connections and along the lateral surfaces of the piles. This phenomenon is not observed in the P-1 diagram due to the rigid connection of the piles with the cap and their smaller horizontal displacements. Under identical ultimate horizontal and vertical loads, the horizontal displacement of P-2 was 4 times greater than that of P-1, and accordingly, the stiffness of the latter is 4 times higher.

As seen in Figure 2, the experimental "load-displacement" diagrams for pile caps P-1 and P-2 are satisfactorily described by a linear relationship obtained from calculations using two methodologies: Zavriev K.S. and Aubakirov A.T. These methodologies assume that the subgrade modulus varies linearly with depth, starting from zero at the surface, based on an equivalent cantilever scheme. However, the influence of vertical load on pile deformability was not taken into account, which can lead to significant errors during the plastic stage of pile performance (second-order effect) in conjunction with soil stiffness.

Dynamic tests of pile caps. Figure 3 shows the recording of free vibrations of pile cap fragments recorded by a Geiger vibrograph, obtained during the instantaneous release of the horizontal load Ph applied by a jack DG-63 (630kN) via a guy rope.

Table 4 presents the values of applied horizontal loads, displacements, natural vibration periods, and damping decrements for the two types of pile caps. It is evident from these values that the deformability, natural vibration periods, and dissipative characteristics of P-2 were greater compared to P-1. The measured values of the dynamic characteristics of the caps obtained with the measuring instruments—electronic VBP and mechanical Geiger vibrographs—show excellent agreement (within 3%), which confirms their reliability.

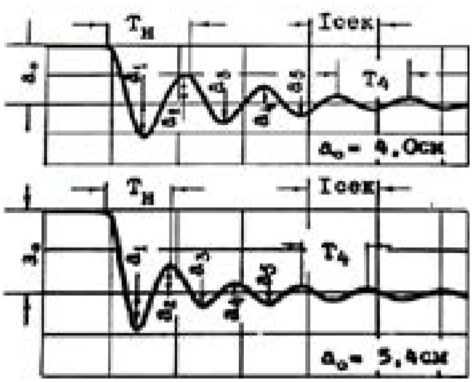

Figure 3. Free vibration recordings of pile caps captured by a Geiger vibrograph.

A general comparison of the performance of single pile No. 4 and an identical pile (in terms of reinforcement, cross-sections, and concrete grade) within pile cap P-2 shows that the damping decrement of the latter increased by 0.63 / 0.57 = 1.11 times, excluding certain influences of dynamic loading. This increase in the dissipative characteristics of the piles within pile cap P-2 is explained by the additional influence of dry friction forces in the hinges.

Table 4. Dynamic Test Results.

Pile cap	Vibro-sensor type	Horizontal load and displacement		Natural vibration period		Logarithmic damping decrement, δ
		P_h, kN	S_h, cm	T_{start}, sec	T,sec	
P-1	VBP	208	1.33	0.56	0.53	0.36
		295	2.06	0.61	0.57	
		347	2.55	0.66	0.60	
		383	3.13	0.67	0.62	
		Mean value of VBP (Large displacement vibrograph)			**0.58**	
	Geiger Vibrograph	208	1.33	0.53	0.51	0.39
		295	2.06	0.58	0.55	
		347	2.55	0.61	0.58	
		383	3.13	0.65	0.62	
		Mean value of Geiger Vibrograph			**0.57**	
P-2	VBP	123	2.06	1.1	0.96	0.63
		150	3.91	1.2	1.05	
		248	6.16	1.3	1.1	
		302,5	8.23	1.36	1.16	
		Mean value of VBP (Large displacement vibrograph)			**1.07**	
	Geiger Vibrograph	123	2.06	1.07	0.95	0.63
		150	3.91	1.23	1.09	
		248	6.16	1.39	1.19	
		302,5	8.23	1.49	1,36	
		Mean value of Geiger Vibrograph			1.1	

In P-1, the opposite trend is observed, i.e., a decrease in the damping decrement compared to single pile No. 5 by 0.39 / 0.61 = 0.64 is noted, which demonstrates the influence of the rigid fixity of the pile heads in the cap.

Seismic-blast impacts. Testing of the pile caps for seismic-blast impacts in the second series of stronger 10-magnitude blasts was conducted using delayed explosions of three rows of boreholes at 1 and 1.5-second intervals.

Table 5 presents the key experimental data obtained from seismic-blast impacts. A comparison of the dynamic parameters (periods and damping decrements) for pile caps P-1 and P-2 across dynamic and seismic-blast tests yielded the following results:

– Under 8-magnitude impact: Natural vibration periods were *T = 0.75 s for P-2 and T = 0.45s* for P-1 *(first series of blasts).*

– Under 10-magnitude impact: Natural vibration periods were *T=1.05s* for P-2*; and T=0.5s* for

P-1*,* damping decrements were *δ=0.65* for P-2, and *δ=0.49* for P-1 *(second series of blasts)*.

When comparing seismic-blast impacts to dynamic tests, the period for P-1 decreased by up to 12%, while *δ* increased by up to 26%. For P-2, the differences in these values were negligible *(4% difference in periods and 3% in damping decrements).*

Consequently, the dynamic characteristics of P-2 obtained during seismic-blast impacts show good agreement with the results of the dynamic tests.

Table 5. Results of pile cap testing under seismic-blast impacts.

Cap №	Acceleration sensor locations	Average maximum acceleration, mm/s2	Natural vibration period, s	Logarithmic damping decrement
P-1	Soil Pile cap	8232 6500	0.5	0.49
P-2	Soil Pile cap	9894 2040	1.05	0.65

Conclusion. The results of comprehensive experimental studies have demonstrated enhanced seismic isolation and dissipative characteristics of pile foundations with hinged connections between the pile heads and the high pile cap compared to rigid connections. Specifically, the logarithmic damping decrement of P-2 exceeded that of P-1 by 1.6 times, while horizontal displacements were 4 times greater.

The seismic-blast impact results showed good convergence with the experimental data from dynamic testing for pile cap P-2.

Overall, the use of pile foundations with hinged connections between pile heads and a high pile cap in construction allows for a significant reduction in seismic loads on buildings–by 2 to 4 times–depending on soil conditions and the characteristics of seismic impacts. This type of foundation is an effective and reliable seismic isolation solution that does not involve significant technological complexity in construction compared to traditional foundations.

The results of these comprehensive experimental studies can be utilized to improve pile foundations with hinged connections for various structural systems and building heights.

It is recommended to use pile foundations with hinged connections in earthquake-resistant construction in combination with various types of dampers, taking into account soil conditions, building structural systems, and seismic impact characteristics.

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